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SOME CAUSES OF ORE SHOOTS.

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GENERAL STATEMENT.

The subject of ore shoots is so closely connected with that of the origin of ore deposits, that the one cannot be intelligently discussed without more or less reference to the other; but the intention in the present article is to confine the discussion as much as possible to the causes that lead to the concentration of certain valuable materials in rich spots in ore deposits, and not to discuss the original sources of the materials of the ore. Moreover, the following remarks relate largely to ore shoots in fissures and other more or less deep-seated positions.

In most ore deposits, the ore and the gangue vary in degree of

admixture from places where the deposit is largely ore with a little gangue to places where it is largely gangue with a little ore. It is rare that ore of even approximately uniform character occurs throughout a deposit, and the richer material is generally in bodies of varying size, continuity and shape. When small, these bodies are known as "nests," "bunches" or "pockets," but the larger or richer ones are called "ore shoots," sometimes also "ore courses" or "pay streaks." When conditions have been unusually favorable, we have those large and immensely valuable ore shoots known to the miner as "bonanzas," which have produced the wealth of many of the world's famous mines.

In its most restricted sense, the term ore shoot applies to a part of a deposit richer in certain metalliferous[1] contents than the adjoining parts, the latter being composed of gangue with perhaps more or less disseminated ore. The term, however, is equally applicable to the not unusual occurrence of an isolated body of ore, more or less steeply inclined in a fissure or other position, surrounded simply by country rock, with no other gangue materials adjacent. Such bodies are often known as "chimneys," "pipes" or "necks." Among miners the term ore shoot is also often applied to places where there is a widening of the deposit and the ore is more abundant than elsewhere, though not necessarily of higher grade.

The typical ore shoot is of a more or less columnar shape, dipping vertically or at a steep angle; but most shoots are less regular in form and some are strikingly irregular, protruding and receding on all sides, thinning down in some places to a narrow neck, in others widening into great dimensions and throwing out long arms from the main body. Some ore shoots instead of dipping steeply, lie almost horizontally or meander up and down. These forms are especially characteristic of those shoots resulting from superficial alteration, as described later. Some ore shoots which originally dipped steeply have been tilted by the folding of the enclosing rocks, and now occupy various posi-

[1] The term shoot is generally applied to metalliferous deposits, but there is no reason why it should not also be applied to non-metallic deposits.

tions of incline. Some shoots form lenticular masses, following a fissure for many feet along its course, and finally thinning out at either end into leaner ore or gangue. In fact sometimes a whole vein is composed of rich ore, and in such a case it is, in a sense, as much an ore shoot as the forms already described; but the term is usually applied to a more or less circumscribed body of ore, and it is this conception of its circumscribed character, in addition to the greater value of its contents as compared with the enclosing materials, that distinguishes an ore shoot from a whole vein of rich ore.

Ore shoots may crop out at the surface or may be found at a greater or less distance below the surface. In depth they may continue for great distances, or they may terminate at less depths and may or may not be succeeded by other shoots below. Where several parallel veins intersect a certain stratum in a formation which encourages ore deposition, such as a limestone or other stratum to be discussed later, an accumulation of ore in a shoot may occur at the point where each vein intersects this special stratum. Thus the shoots in the different veins will occur along the line of the strike of that stratum. In the same way if several parallel veins cross a certain fissure which promotes ore deposition, as explained further on, the shoots in the different veins will occur along the line of that fissure. This form of symmetry in the occurrence of shoots is known among miners as "ore against ore."

The occurrence of ore shoots is due to the varying chemical and physical conditions in different places at the time of ore deposition. Van Hise[1] classifies them in three groups, those "largely explained (A) by structural features, (B) by the influence of the wall rocks, and (C) by a secondary concentration by descending waters." Irving[2] classifies ore shoots as "shoots of

[1] C. R. Van Hise, "Some Principles Controlling the Deposition of Ores," *Trans. Am. Inst. Mng. Eng.*, Vol. XXX., pp. 27–177.

[2] J. D. Irving, "The Localization of Values in Ore Bodies and the Occurrence of Shoots in Metalliferous Deposits," ECONOMIC GEOLOGY, Vol. III., 1908, pp. 143–154.

variation" and "shoots of occurrence," the former being shoots that vary from the enclosing material only in relative richness in ore, and the latter class being shoots occurring in isolated positions with no other ore of any kind about them. Winchell[1] classifies ore shoots as "paragenetic shoots," or shoots developed mostly at the time of the original formation of the ore deposit enclosing them, and "postgenetic shoots," or shoots developed mostly after the original formation of the enclosing ore deposit.

The great difficulty in classifying ore shoots is that many totally different causes have often combined to produce any one shoot, and the evidence of some of these causes may have been much obscured or even obliterated since that time, so that the determination of just what cause has been uppermost in influence is often impossible. Thus a given shoot may clearly owe its presence, in part at least, to the replaceable character of the wall rock, but if the structural features in the same spot were also favorable to ore deposition, it might be difficult to decide which influence had been the more important. If in addition to this, the shoot had been clearly enriched by later alteration from above, the complication would be still further enhanced. In the present paper, instead of classifying ore shoots, the various influences tending to produce them will be grouped under separate headings.

A most important point, however, must be made clear before going on with this discussion, and this is that the influences to be described as sometimes causing ore shoots, do not always operate in this way. As a matter of fact, most of these influences seem to be practically without effect in far more cases than they have effect, and in some cases they have actually been injurious to the quantity or quality, or both, of the ore. In the cases where they have been favorable to the unusual concentration of ore, however, their effect has often been so very marked that it cannot be doubted.

[1] H. V. Winchell, "The Localization of Values in Ore Bodies and the Occurrence of Shoots in Metalliferous Deposits," Economic Geology, Vol. III., 1908, pp. 425–428.

INFLUENCE OF MAGMATIC SEGREGATION.[1]

Many bodies of ore occurring in more or less irregular masses in rocks of igneous origin, are supposed by some geologists to have been formed by segregation during the cooling of the magma in which they are found. Other geologists believe that a tendency to such segregation may have occurred during the cooling, but that the ore-bodies as now found are not altogether due to magmatic segregation, and have been at least assisted in their formation by the later action of vapors and hot waters. The theory of the magmatic origin of certain classes of ore deposits has been gaining much strength in recent years and in many cases is now very generally admitted.

Professor Vogt,[2] of Kristiania, Norway, has for years advocated the magmatic origin of various basic segregations, including many deposits of titaniferous magnetite and other ores, in Norway, Sweden and elsewhere. Among other deposits now generally supposed to have had a similar origin, may be mentioned the titaniferous iron ores of Cumberland in Rhode Island, those in the gabbro of the Adirondacks and of Minnesota, the native iron in the basalt of Greenland, perhaps some of the copper and nickel deposits of Sudbury in Canada and the nickel deposits of Lancaster Gap in Pennsylvania, as well as many other similar occurrences.

Deposits of this kind are very different from deposits of more clearly aqueous origin. The ore is generally in more or less irregular pockets, bunches or larger bodies enclosed on all sides by country rock, not dependent on the presence of a fissure, a contact, an easily replaceable rock or any of the other usual positions favorable for ore deposition. In such respects they represent a distinct class of ore shoots. Some geologists even

[1] The class of shoots represented by magmatic segregation is small compared with the deposits formed by the various processes of aqueous concentration to be described later, but they are mentioned first because, in some cases, they may have been one of the sources of supply of metalliferous materials in later aqueous concentrations.

[2] J. H. L. Vogt, "Zeitschrift für praktische Geologie," numerous papers from 1893 to present time.

believe that certain gold-bearing quartz deposits occurring in fissures, were formed from the siliceous residue of magmas out of which most of the basic materials had previously crystallized.[1]

INFLUENCE OF LOCAL EMANATIONS OF ORE-BEARING SOLUTIONS.

One of the most common modes of occurrence of ore is in fissures, yet the existence of a fissure by no means indicates the presence of ore. Most all regious, especially those that have been subjected to orogenic movements, are more or less fissured, and sometimes intensely so; but the fissures that have become the receptacles for any important quantities of ore are the rare exceptions and not the rule. The other fissures may be filled with calcite, quartz, silicates, fluorite, barite and other common gangue minerals, or they may be empty or partly filled with clay selvage and other products derived from the rubbing and the decay of their walls, or they may be lined along the walls with films of siliceous, calcareous, ferruginous or other incrustations.

When the barren fissures are younger than the ore-bearing fissues, the absence of ore may be because they were not formed until ore deposition had ceased; but in many cases the barren fissures are as old or older than the ore-bearing fissures, and moreover fissures frequently carry ore in some parts and are barren in other parts. It seems probable that the presence or absence of ore is often determined by the presence or absence of conditions suitable for its precipitation from ore-bearing solutions, but undoubtedly it is sometimes due to the ore-bearing solutions following only certain channels and not others. They probably often rose as fumaroles or thermal springs, spreading along some fissures and not others, and even in the same fissure often rising along narrow chimney-shaped channels, while elsewhere other waters circulated.

In many regions of both cold and thermal springs at the present time, a characteristic feature is the occurrence, in close

[1] J. E. Spurr, "Ore Deposits of the Silver Peak Quadrangle, Nevada," U. S. Geol. Survey, Professional Paper, No. 55. Also, "A Theory of Ore Deposition," Economic Geology, Vol. II., pp. 781–795.

proximity to each other, of waters heavily charged with one kind of mineral matter and waters heavily charged with another kind, as well as waters carrying very little mineral matter of any kind. Such a condition is especially characteristic of regions of subsiding igneous activity, and in it we see a reason why the vents of some extinct springs should be filled with mineral matter of varying kinds and others should carry little or none.

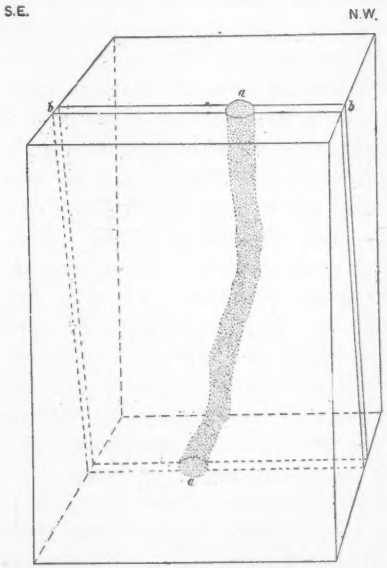

FIG. 5. Stereogram showing ore shoot at Anna Lee Mine, Cripple Creek, Colorado, after R. A. F. Penrose, Jr., 16th Ann. Rept. U. S. Geol. Survey, 1894–5, pt. II.

Where the mineral matter in the spring was ore-making material, an ore shoot might be formed; where it was gangue-making material, a deposit of gangue minerals might result, and between these extremes all degrees of admixture might occur. These various conditions offer a possible reason for the occurrence of ore in shoots along certain narrow limits, such as are represented by the channels of thermal springs.

A typical case of a shoot filling a purely local channel is seen in the long columnar ore body at the Anna Lee mine in Cripple Creek, which varied from 12 to 15 feet in diameter and was followed down almost vertically for some hundreds of feet (see Fig. 5). At Kalgoorlie in West Australia, several mines, including the Brown Hill, Oroya Brown Hill, Oroya North Block and Iron Duke, are located on a large chimney of gold ore which may have been formed in a somewhat similar manner. This shoot, when seen by the writer in 1904, was from 30 to 50 feet in width and had been followed on the incline for some 3,000 feet, corresponding to a vertical distance of about 1,000 feet. This deposit differs from the other gold deposits in the Kalgoorlie district, most of which partake more of the nature of veins in fissures. Again the Silver King mine in southern Arizona, is located on a chimney shaped body of quartz with seams of ore radiating off from it into the country rock.

In some places small volcanic necks or vents have been filled with igneous materials which have later been impregnated with ore, forming chimney-shaped ore shoots. A notable case of this is the old Bassick mine[1] (see Fig. 6) near Rosita, Colorado, which is a volcanic vent filled with fragments of andesite, granite, gneiss, etc., all more or less cemented and encrusted with sulphides. The ore was probably deposited from hot solutions which followed the subsidence of the igneous activity that produced the vent. The Etta tin mine in the Black Hills of South Dakota belongs to a somewhat similar class. It is an intrusive granitic neck which has been later impregnated with cassiterite and other minerals, probably by fumarole action. The diamonds of South Africa occur in somewhat similarly shaped necks, locally called "pipes," filled with a brecciated mass of igneous material.[2] The Cripple Creek district of Colorado is on a volcanic vent

[1] S. F. Emmons, "The Mines of Custer County, Colorado," 17th Ann. Rept. U. S. Geol. Survey, pt. 2, pp. 405–472. Also, Whitman Cross, "Geology of Silver Cliff and the Rosita Hills," 17th Ann. Rept. U. S. Geol. Survey, pt. 2, pp. 263–403.

[2] R. A. F. Penrose, Jr., "The Premier Diamond Mine, Transvaal, South Africa," Economic Geology, Vol. II., pp. 275–284.

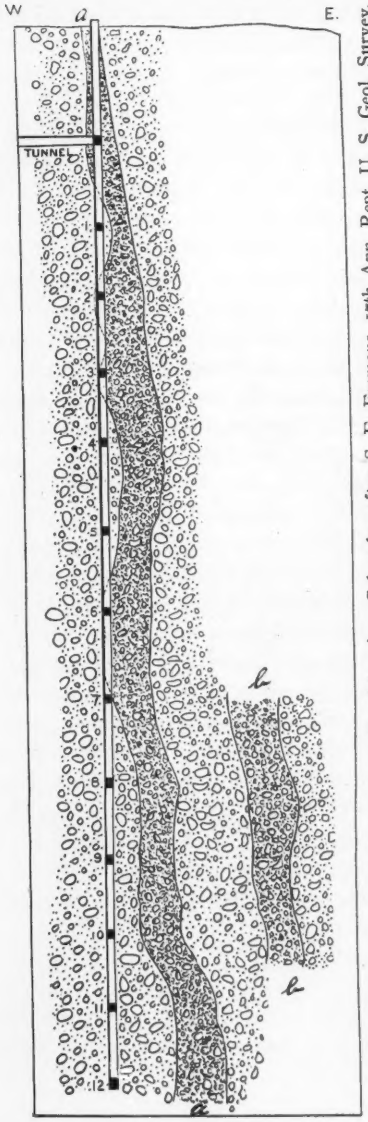

FIG. 6. Section showing ore shoot at the Bassick mine, Colorado, after S. F. Emmons, 17th Ann. Rept. U. S. Geol. Survey. *a–a* = ore shoot intersecting igneous materials. *b–b* = subordinate ore shoot.

filled with breccia, which in turn is honeycombed with gold-bearing veins; but in this case the vent is so large that the chimney character is not so noticeable as in narrower necks.

INFLUENCE OF GASEOUS EMANATIONS.

The presence of large quantities of gases in coal mines is a generally recognized matter, but the occurrence of gases in metalliferous mines has been much less studied, probably because the gases are in smaller quantities and are less apt to be dangerous; yet in some metalliferous mines they often cause much inconvenience and sometimes danger. They are found issuing from different vents in underground workings, often with considerable force, and consist most commonly of carbonic acid and hydrogen sulphide, but not infrequently of sulphur dioxide, methane (marsh gas), nitrogen and sometimes other gases.

Where these gaseous emanations occur in mines in igneous rocks, they are probably often the remnant of the fumarole or hot spring action that produced the ore deposit, just as the fumaroles were the remnant of the subsiding igneous activity that produced the rocks of the region. Gases are, therefore, less apt to occur in ore deposits where long intervals have elapsed since their formation than in deposits of younger age. In the older deposits, carbonic acid gas is the most common one found, while in younger deposits various other gases also may occur. Gases may also occur in some ore deposits from chemical decomposition of certain minerals, unassisted by any igneous influences.

Certain gases may have a precipitating effect on an ore-bearing solution, and where a jet of such a gas occurs in the path of a solution, a shoot may be formed, while beyond the limit of the effect of the gas, deposition might cease. Gaseous emanations, when evolved with sufficient strength, may also have considerable influence during the formation of an ore deposit in forcing the ore-bearing solutions along certain courses and not along others, so that the solutions pass upward within only certain narrow limits. By such action they may often have much to do with the position of fumaroles and springs, and hence with the formation of shoots.

Emanations of carbonic acid gas are notably abundant in some of the mines of Cripple Creek in Colorado, of the Thames or Hauraki district of the north island of New Zealand and many other regions. In the mines of Sulphur Bank in California, in addition to carbonic acid gas, there are hydrogen sulphide, marsh gas, nitrogen, etc., while at Steamboat Springs in Nevada the gases are mostly carbonic acid and hydrogen sulphide.

INFLUENCE OF THE STRUCTURE OF FISSURES.

As explained on page 114 a fissure may differ much in character as it passes from one rock to another, yet even in the same rock its character may vary from spot to spot, both on account of the nature of the movement that produced it and on account of the structural condition of the rock. A fissure passing through a horizontal or regularly dipping rock may have a very different, and generally much more uniform character than in the same rock much disturbed and folded. A fissure, therefore, whether intersecting different rocks or the same rock, may in one place be a clean cut break, in another a zone of brecciation, or a series of parallel fissures, or a series of more or less shattered areas connected by comparatively regular breaks, or may assume various other more or less complicated forms. When there has been a fault movement of greater or less extent along a fissure, different parts of the rock may be brought into juxtaposition, leaving cavities separated by places where the walls are close together.

In these various ways numerous cavities may be formed, which may influence the position of ore shoots, not only because they offer the physical space for deposition, but because they afford a better chance for admixture with other solutions which may cause precipitation,[1] and also because they produce a slackening of speed in the ore-bearing solutions that enter them, and may thus cause a deposition of ore which might not occur where the solu-

[1] On the other hand, open spaces may be unfavorable places for deposition when they happen to be the channels for waters which have no precipitating action on the ore-bearing solution, and which simply dilute the latter and thus tend to impede or prevent deposition.

tions were rapidly moving. In brecciated areas, ore shoots are apt to occur not only because of the open spaces, but also because there is better opportunity for replacement than in the solid sides of the fissure.

Obstructions, as well as openings, in a fissure may in some cases have an influence on the position of ore shoots. Obstructions may occur where the walls are locally pressed tightly together, or where the fissure makes a curve or is faulted, or where the decay and rubbing of the walls produce clay selvage, or gouge, which collects and forms obstacles, leaving other parts of the fissure open. Obstructions may also be found in a fissure in cases where the gangue comes from a different source than the ore, perhaps from the adjacent rocks, and partly fills the fissure before ore is deposited in the remaining space. Obstructions may also occur where the fissure passes from a rock in which it has caused a pronounced break to a more plastic rock in which it has had very little effect, or even has disappeared, as described on page 114.

Any of these obstructions may influence the formation of ore shoots by locally checking the speed of the ore-bearing solutions that come in contact with them, thus encouraging deposition, or by forcing them into other parts of the fissure not obstructed and thus confining deposition to circumscribed positions, or by forcing them into the wall rock, forming local accumulations of ore either by replacement or by filling interstices and cracks.

A notable case of the different aspects of a fissure in different parts, is seen in the great faults on which the Ontario silver mine and other mines at Park City, Utah, are located. The principal fissure in the Ontario mine intersects chiefly limestones and quartzites, with some shale, in the vicinity of an igneous contact. The fissure is sometimes a clean cut break, sometimes it forks and comes together farther on, enclosing great "horses" of rock, and sometimes it is represented by a zone of intense brecciation. In some places the walls come close together and but little ore intervenes, in others they widen out and larger bodies of ore occur; while very characteristic features are zones of brecciation varying from a few feet to many feet in width, and

impregnated with ore. In some places the ore cements this zone into a solid mass, in others it occurs in thin seams meandering through it and separated by areas of loose breccia, forming an open porous vein filling. The fragments of the breccia are mostly limestone and quartzite and both materials have been more or less replaced by ore, as have also the walls of the fissure and the "horses" of rock. In places the ore runs out from the main vein for some distance along lines of bedding in the country rock, forming collateral shoots, and gradually tapering out.

The Comstock lode at Virginia City in Nevada is another case where the varying character of a great fault fissure affects the quantity of ore from place to place; and in fact many of the important mines of the world illustrate similar phenomena. On the other hand, the Butte City copper mines and some of the silver-lead mines of the Cœur d'Alene district of Idaho represent conditions in fissures in which there has been but little displacement and where the ore shoots are mostly replacements of wall rock.

In some places the folds in rocks offer structural conditions that influence the position of ore shoots, even where there is no well defined fissure. Thus at Bendigo in Australia, the gold ore has accumulated in the crests of anticlinal folds, in sandstone strata immediately underlying slate, in bodies known to the miners as "saddle reefs."[1] The sandstone, perhaps more or less shattered by the folding, has offered a pervious channel, and the overlying less pervious slate has confined the ascending solutions to it. Under favorable conditions, ore may also accumulate in a similar manner in synclinal troughs. The latter, however, are better adapted for the accumulation of ore from descending solutions, and some of the iron deposits of the Lake Superior region are accumulations in such positions, due to downward moving solutions meeting an impervious base,[2] instead of upward moving solutions meeting an impervious roof, as at Bendigo.

[1] T. A. Rickard, "The Origin of the Gold-Bearing Quartz of the Bendigo Reefs," *Am. Inst. Mng. Eng.*, Vol. XXII., pp. 289–321.

[2] C. R. Van Hise, "The Iron Ore Deposits of the Lake Superior Region," 21st Ann. Rept. U. S. Geol. Survey, pt. 3, pp. 305–434.

INFLUENCE OF INTERSECTING FISSURES.

There is a popular impression among miners that ore shoots are especially likely to occur where one vein intersects another, and sometimes this is true; but as with most conditions under which ore shoots may be formed, the actual occurrence of the shoot is the exception and not the rule. Nevertheless important ore shoots sometimes do occur at vein intersections; and moreover they also sometimes occur where a vein of ore is cut by a vein of gangue material or by a barren fissure containing no mineral matter other than rock débris. It is noticeable that this enrichment is not confined to places where strong well-defined fissures cut the ore-bearing fissures, but that it occurs also where smaller cracks or even joint planes intersect them.

The occurrence of a shoot at the intersections of two ore-bearing veins may be due to the fact that the rock was more shattered than usual at such positions[1] and permitted a more ready and copious supply of ore-bearing solutions than elsewhere, or it may be due to the fact that where solutions in two fissures meet, their speed is slackened and a deposition of ore may occur which would not have taken place from more rapidly moving solutions. In the same way, if one fissure is faulted by another, deposition of ore may occur as the result of the checking of the progress of the solutions at the fault.

When a shoot occurs at the intersection of a fissure that carries ore and one that is barren or carries only gangue minerals, the latter may have acted as a channel for certain solutions different from the solutions in the main fissure, and of such a character as to cause a precipitation of mineral matter from the solutions in the main fissure, which might not otherwise have occurred. In other cases the influence of the cross fissure may have been purely mechanical, deflecting the metalliferous solutions and confining or guiding them to advantageous positions of deposition. Sometimes cross fissures, instead of supplying solutions, may act

[1] This action is most apt to occur where the fissures meet at low angles, thus forming wedge-shaped bodies of rock which are more easily shattered on their edges, than the blocks formed by fissures coming together at high angles.

as channels through which the ore-bearing solutions in the main channel are carried off into the country rock, depositing "stringers" of ore which gradually taper out at a short distance. Where a number of cross fissures intersect the ore-bearing fissure and also each other, they form blocks of country rock in the walls, which may be replaced by ore in much the same way as the "horses" of rock described on page 108.

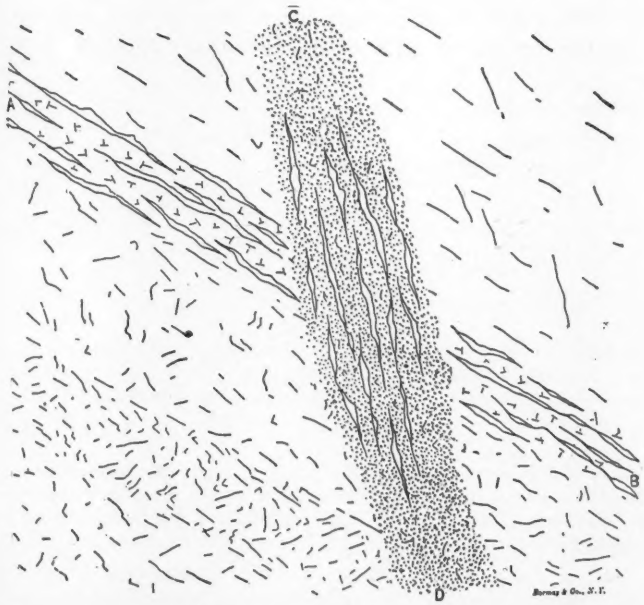

FIG. 7. Section showing the occurrence of ore shoot at the intersection of veins at the Moanataeri mine, New Zealand, after T. A. Rickard, Trans Amer. Inst. Mng., Vol. XXXI. *A–B* = vein. *C–D* = vein.

An effect similar to that caused by a cross fissure is sometimes produced where the main ore-bearing fissure crosses an especially well marked line of stratification in sedimentary rocks, this line having often the same influence as a cross fissure.

The favorable influence of intersecting veins and fissures on ore shoots is seen in many well known mining districts, such as Aspen and Cripple Creek in Colorado, the gold regions of California, the Mississippi Valley lead and zinc regions, Freiberg in Germany, the Hauraki district of New Zealand and many other places. Even in such regions, however, the intersections do not always have this effect, and it is the exception and not the rule to find it. Much more often they have no effect, and sometimes they have a bad effect, perhaps due to the fact that they may allow the leaching of some of the normal ore contents of the

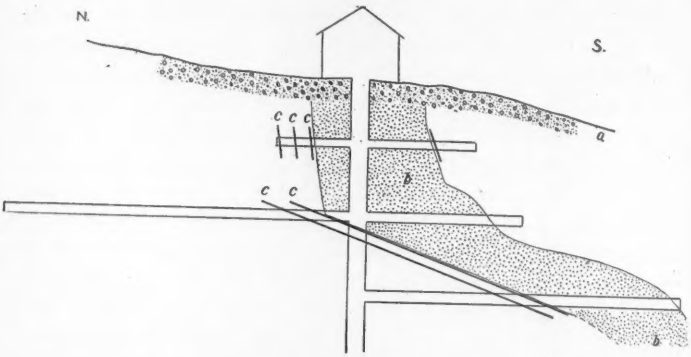

FIG. 4. Longitudinal section showing ore shoot at the intersection of fissures in the C. O. D. mine, Cripple Creek, Colorado, after R. A. F. Penrose, Jr., 16th Ann. Rept. U. S. Geol. Survey, pt II. a = surface débris; b = ore shoot; c, c, c = cross fissures.

vein. When, however, the influence has been favorable, the result is often so very striking that this cause of ore shoots must be considered one of the most important of all causes[1] (see Figs. 7, 8 and 9).

Frequently cross fissures intersect a vein after it has been

[1] Where several parallel veins are intersected by a cross fissure that has promoted deposition of ore, the shoots in each vein occupy a position in line with the cross fissure, producing the effect known among miners as "ore against ore" (see page 99).

formed, and may cause an enrichment of the original deposit by the influx of fresh ore-bearing solutions, just as in the case of veins fissured longitudinally by later breaks (see page 129).

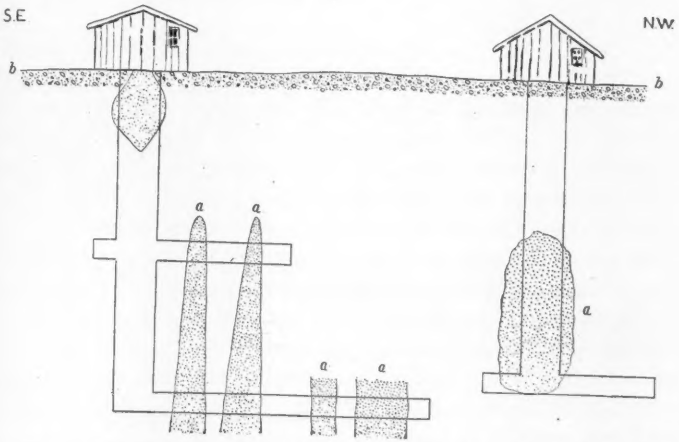

FIG. 9. Longitudinal section showing occurrence of ore shoots in the Ida May mine, Cripple Creek, Colorado, after R. A. F. Penrose, Jr., 16th Ann. Rept. U. S. Geol. Survey, 1894–5, pt. II. *a*, *a* = ore shoots; *b* = surface debris. Scale: 1 inch = 100 feet.

INFLUENCE OF THE WALL ROCK OF FISSURES.

In many regions of fissure veins, the wall rock has a marked effect on the quantity of ore present, and sometimes on the nature of the ore, thus greatly influencing the distribution of ore shoots. A fissure intersecting different rocks may carry an abundance of ore in one rock and little or none in another, or may carry a certain ore in one rock and a different ore in another. These occurrences were once used by the strict lateral secretionists as arguments that the ore had been derived from the rocks immediately adjacent, and in some few cases, perhaps, this argument may have force, but in most cases the effect is probably due to the action of the wall rock, or the waters draining from it, on the ore-bearing solutions. The quantity of ore is the feature

most generally influenced under these conditions, but some notable cases occur where different metals are found in different parts of a fissure, the change being coincident with a change in wall rock.

INFLUENCE OF THE PHYSICAL CHARACTER OF THE WALL ROCK OF FISSURES.

A given rock may be more open and porous than those associated with it, and if cut by a fissure, it may offer a better opportunity for the infiltration of ore-bearing solutions than the others, thus encouraging the formation of shoots. Moreover, a fissure intersecting different rocks often has a very different character in one than in another. In one rock it may be a single, sharp, clean-cut break, in another it may fade out and disappear, in another it may be shattered and brecciated, and in still another, it may separate into a number of more or less parallel fissures, forming a zone of fissuring; or many other forms may be developed, depending on the varying physical character of the different rocks.

The more irregular and broken fissures offer better channels for percolating solutions than the clean cut fissures with the two sides pressing close together, and, therefore, the rocks that produce the former conditions are frequently more apt to contain ore than the latter. On the other hand, if a fissure breaks up into a number of small fissures and the rock is not subject to replacement, the ore may sometimes be too much scattered to be of value.

Excellent examples of the change in the physical character of fissures as they pass from one rock to another are seen in Cripple Creek, Colorado, where fissures are often well marked in certain rocks, while when they pass into more plastic materials they become much smaller or even disappear.[1] Somewhat similar cases are described by Irving and Emmons[2] in the Black Hills

[1] R. A. F. Penrose, Jr., "Mining Geology of the Cripple Creek District, Colorado," 16th Ann. Rept. U. S. Geol. Survey, Pt. II., p. 144.

[2] J. D. Irving and S. F. Emmons, "Economic Resources of the Northern Black Hills," U. S. Geol. Survey, Professional Paper, No. 26, pt. 2.

of South Dakota, by Rickard[1] at Rico in Colorado, by Purington at Telluride in Colorado,[2] by Spurr in the Mercur district of Utah,[3] by Beck[4] near Freiberg, Germany, by De La Bêche[5] in Cornwall in England, by Von Cotta[6] at Przibram in Bohemia.

INFLUENCE OF THE CHEMICAL CHARACTER OF THE WALL ROCK OF FISSURES.

The chemical character of the wall rock of a fissure often has far more influence on the deposition of ore than the purely physical character, and frequently determines the existence or non-existence of ore in a fissure, thus influencing in a marked manner the distribution of ore shoots. The rock in which a certain ore is abundant may have caused precipitation by a direct chemical effect on certain constituents of the ore-bearing solutions; or waters draining from this special rock and impregnated with the substance of it, or with other materials, may have had a similar effect. The rock may also have been susceptible to replacement by certain materials in the ore-bearing solutions, thus encouraging the concentration of ore by giving space for its accumulation. This replacement may have gone on by the removal of certain ingredients of the rock by the ore-bearing solutions and the substitution of certain other ingredients from the same solutions, practically simultaneously, and in this case the process represents that form of metamorphism known as metasomatism. In many cases, however, the replacement has gone on by the removal of certain ingredients of the rocks by one solution and the later substitution of other ingredients by the same or another solution. In this latter process, the change may

[1] T. A. Rickard, "The Enterprise Mine, Rico, Colorado," *Trans. Am. Inst. Mng. Eng.*, Vol. XXVI., pp. 976–977.

[2] C. W. Purington, "Ore-Horizons in the veins of the San Juan Mountains, Colorado," Economic Geology, Vol. I., pp. 129–133.

[3] J. E. Spurr, "Economic Geology of the Mercur Mining District, Utah," 16th Ann. Rept. U. S. Geol. Survey, pt. 2, pp. 452–454.

[4] R. Beck, "The Nature of Ore Deposits," Weed's translation, Vol. I., pp. 119–120.

[5] H. T. De La Beche, "The Geological Observer" (Philadelphia, 1851), pp. 640–641.

[6] B. Von Cotta, "A Treatise on Ore Deposits," Prime's translation, p. 48.

progress particle by particle, in a very minute manner, or cavities of larger size may be formed, and even great chambers may result from the dissolving solutions, and may later become the receptacles for ore.[1]

Limestone.—Many rocks have an influence on ore deposition, but some have much greater influence than others, and of all rock, limestone, including dolomite, has the most generally marked effect. Its influence is due both to the metasomatic replacement of calcium carbonate by materials from the ore-bearing solutions, and to the leaching out of cavities in the limestone and substitution of other materials in the spaces thus formed. Its influence may perhaps sometimes be further increased when, under the action of certain solutions, the calcium carbonate is decomposed chemically, setting free carbonic acid, which may add greatly to the power of the solutions to dissolve limestone, thus increasing the number and size of the cavities available as receptacles of ore.

In a fissure crossing a series of interbedded limestones, sandstones, slates, etc., or limestones cut by igneous rocks, the preference of ore for the limestone rather than for the other rocks is often very marked, and large ore shoots often occur where a fissure passes through this rock, while where it passes through other rocks the ore body is often much contracted. If a number of limestone strata separated by other strata occur, we may find a series of alternating wide places and narrow places in the deposit. The ore shoots in the limestone are often especially large at the contact of that rock with a less easily affected rock, a fact due probably to the slackening of speed and to the enforced accumulation of ore-bearing solutions at such places (see Fig. 10).

Examples of the influence of limestone on ore deposition are seen at many places in the world, especially in silver, lead, copper and iron, and sometimes gold and other deposits. Among such

[1] Where several parallel veins cross a formation that encourages ore deposition, the bodies of ore in each vein occupy a position in line with that formation, producing the effect known among miners as "ore against ore" (see page 99).

instances are Leadville and the San Juan region in Colorado; Bisbee, Clifton, Globe, and Tombstone in Arizona; Silver City and Lake Valley in New Mexico; Park City and Eureka in Utah; Eureka in Nevada; Sierra Mojada in Mexico; various districts in British Columbia, and many other parts of North America. Similar occurrences are seen at Cumberland and Derbyshire in England, and many places in Chile and other parts of the world. Among the more common metals, many iron deposits are due to a replacement of limestone, as seen in some of the lower Paleozoic deposits in the Appalachian Mountains, at the Calumet and

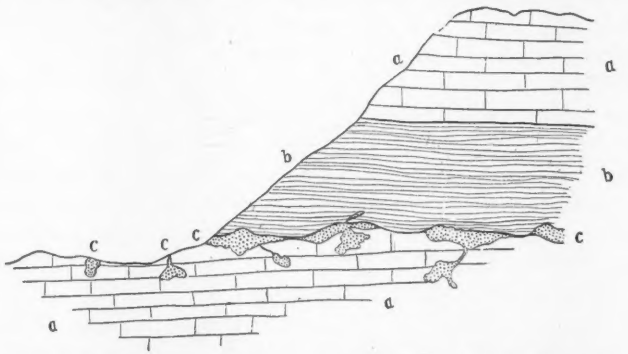

FIG. 10. Sketch section showing occurrence of ore shoots in limestone at contact of overlying shale at the Bremen mine near Silver City, New Mexico, by R. A. F. Penrose, Jr. *a*, *a* = limestone; *b*, *b* = shale; *c*, *c*, *c* = ore.

the Orient mines in Colorado, and the Bilbao mines in Spain, at some of the mines of the Island of Elba and many other places.

When limestone strata have been turned on end, and fissuring follows the strike, the formation may become so open and porous that large and extensive cavities are formed by the downward percolation of surface waters or the upward percolation of deep seated waters, thus affording ready receptacles for ore shoots. A remarkable instance of such leaching is seen at Eureka, in the Tintic district of Utah, where a steeply dipping limestone is

impregnated along its strike for a width of sometimes over 500 feet with mineral matter (see Fig. 11). Many noted mines such as the Eureka Hill, Bullion Beck, Gemini, Centennial, etc., are located on this zone of mineralization. In one place on it, in 1894, the writer saw in the underground workings an open natural chamber, formed by leaching, between 200 and 300 feet in length, ten to fifteen feet in width and over 100 feet in depth. This was formed after the deposition of ore, but similar chambers

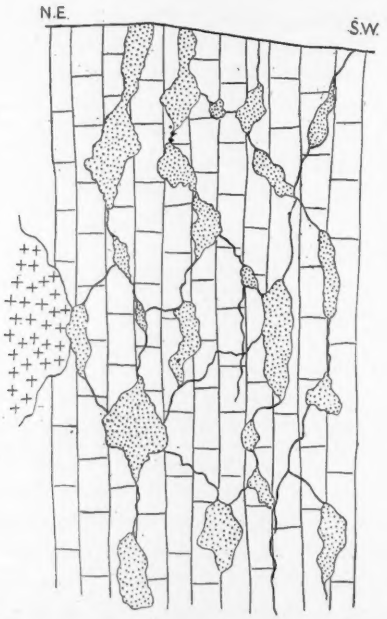

FIG. 11. Sketch section showing a typical occurrence of ore at Eureka, Utah, by R. A. F. Penrose, Jr. Dotted parts indicate ore; the enclosing rock is limestone; on the left is an igneous mass. Scale: 1 inch = 50 feet.

may have been formed before ore deposition and later may have acted as receptacles for ore, in addition to the ore deposited by metasomatic replacement.

Though limestone has, more than any other rock, been instrumental in the formation of ore shoots in various parts of the world, yet like most influences affecting shoots, its action is not universal, and there are many districts in which such rocks appear to have had no influence, while in others they appear to have been actually detrimental to the accumulation of ore. As a rule, however, unless limestone has been proved to have been inert or to have had a negative effect, it is always well to investigate its possible favorable influence on ore deposition.[1]

Siliceous Rocks.—Under the action of certain ore-bearing solutions, siliceous rocks may be extensively replaced, thus forming ore shoots, though such results are not so generally marked as with calcareous rocks. At the principal silver-lead mines in the Cœur d'Alene district in Idaho the ore deposits are mostly a replacement of quartzite and other siliceous rocks by siderite and argentiferous galena, with other minerals in small quantities.[2] Again in the iron districts of the Lake Superior region, Van Hise[3] has shown that many of the rich iron deposits were formed from low grade ferruginous materials and that this concentration progressed largely by the replacement of silica by iron ore. In this case the replacement has occurred on an enormous scale.

In some cases certain silicates in crystalline rocks may be replaced more easily by ore than other silicates or other constituents of the rock, thus influencing shoots in certain rocks containing the replaceable materials.[4]

Organic Matter.—When a vein crosses a formation highly impregnated with organic matter, ore shoots often occur, and

[1] Any rocks containing calcium carbonate, like calcareous sandstones, calcareous shales, etc., tend to have an influence somewhat similar to limestone, on account of the ease with which ore-bearing solutions act on the calcium carbonate in them.

[2] F. L. Ransome and F. C. Calkins, "The Geology and Ore Deposits of the Cœur d'Alene District, Idaho," U. S. Geol. Survey, Professional paper No. 62.

[3] C. R. Van Hise, "The Iron Ore Deposits of the Lake Superior Region," 21st An. Rept. U. S. Geol. Survey, pt. 3, pp. 305–434.

[4] See W. H. Weed, "Influence of Country Rock on Mineral Veins," *Trans. Am. Inst. Mng. Eng.*, Vol. XXXI., pp. 634–653. Also, "Geology of the Little Belt Mountains, Montana," 20th Ann. Rept. U. S. Geol. Survey, Pt. III., pp. 418–420.

this is probably due to the action of the organic matter on ore-bearing solutions, causing precipitation by its reducing action or by other chemical means. Such occurrences are seen in some of the lead and zinc regions of the Upper Mississippi[1] and of Missouri,[2] at Bingham[3] in Utah, and in parts of the mother lode region of California. In northern New Mexico,[4] wood, branches of trees, leaves, etc., are found converted to copper minerals, showing the effect of vegetable matter on copper bearing solutions, and similar occurrences are seen in northern Texas,[5] as well as in many other places in America and Europe. At Freiberg[6] in Germany veins crossing graphitic schist are richer than elsewhere, and at Mansfield[7] in Germany the copper ores are notably rich in bituminous formations. Organic matter is supposed to have had marked effect on ore deposition at Ballarat, Victoria, where a very thin but quite persistent stratum of black slate appears to have caused an increase in ore where veins cross it, and hence is locally known as the "indicator."[8] A similar influence of organic matter is seen at Bendigo in Victoria and at Gympie in Queensland.

Sulphides.—Any rocks heavily charged with iron pyrites or

[1] T. C. Chamberlin, "Geology of Wisconsin," Vol. IV., pp. 547–549. Wm. P. Blake, "The Lead and Zinc Deposits of the Mississippi Valley," *Trans. Am. Inst. Mng. Eng.*, Vol. XXII., pp. 630–631.

[2] W. P. Jenny, "The Chemistry of Ore Deposition," *Trans. Am. Inst. Mng. Eng.*, Vol. XXXIII., pp. 445–498.

[3] J. M. Boutwell, "Genesis of the Ore Deposits at Bingham, Utah," *Trans. Am. Inst. Mng. Eng.*, Vol. XXXVI., pp. 541–580.

[4] F. M. F. Cazin, *Engineering and Mining Journal*, Vol. XXX., p. 381.

[5] E. J. Schmitz, "Copper Ores in the Permian of Texas," *Trans. Am. Inst. Mng. Eng.*, Vol. XXVI., pp. 97–108.

[6] B. Von Cotta, "A Treatise on Ore Deposits," Prime's translation, pp. 46–47.

[7] Von Cotta, *op. cit.*, p. 166.

[8] T. A. Rickard, "The Indicator Vein, Ballarat, Australia," *Trans. Am. Inst. Mng. Eng.*, Vol. XXX., pp. 1004–1019. The "indicator" also contains large quantities of iron sulphide, and some authorities claim that the influence of the "indicator" was due to the action of this on the ore-bearing solutions and not to the action of the carbonaceous matter; but Rickard believes that the carbonaceous matter caused the deposition of the iron sulphide, and that, therefore, it has been, either directly or indirectly, the cause of the increase of ore in the veins crossing it.

other sulphides may have an effect on ore-bearing solutions on account of the precipitating action of the sulphides. This action is analogous to that of sulphides in veins on later ore-bearing solutions, and is further discussed on page 129.

Igneous Rocks.—Many ore deposits in regions of igneous rocks are directly due to the various influences of subsiding igneous activity; but there is a class of ore deposits, and of ore shoots in these deposits, which have been caused simply by the chemical and physical action of certain mineral constituents in igneous rocks on ore-bearing solutions, in a manner analogous to the way certain sedimentary rocks, already described, affect such solutions. Thus in the Lake Superior copper region, the copper occurs with basic volcanic rocks and is supposed to have been precipitated by the action of ferrous compounds in these rocks on copper-bearing solutions.[1] Frequently the copper has more or less replaced the country rock, especially in some of the volcanic conglomerates, in which the open structure allowed a free percolation of metalliferous solutions. In the San Juan region of Colorado, according to Purington, the ore in different strata of andesitic breccia is more abundant in those strata which carry large quantities of basic minerals than in other strata.[2]

These processes of replacement in igneous rocks are often greatly hastened when more or less of the original heat and other accompanying phenomena of subsiding igneous activity still remain. Such may have been the case at the time of deposition of some of the ore at Cripple Creek, Col., where an andesitic breccia, and sometimes other igneous rocks, have been extensively replaced, often forming large ore bodies in the wall rock along very narrow fissures.[3] Again in the tin deposits of Mt. Bischoff,

[1] R. Pumpelly, "Geology of Michigan," Vol. I., Pt. III., p. 43. R. D. Irving, "The Copper-Bearing Rocks of Lake Superior," Mon. U. S. Geol. Survey, No. 5, pp. 420, 425–426.

[2] C. W. Purington, "Ore Horizons in the Veins of the San Juan Mountains, Colorado," Economic Geology, Vol. I., p. 133.

[3] R. A. F. Penrose, Jr., "The Mining Geology of the Cripple Creek District, Colorado," 16th Ann. Rept. U. S. Geol. Survey, Pt. II., 1894–5. Also, W. Lindgren and F. L. Ransome, "Geology of the Gold Deposits of the Cripple Creek District, Colorado," U. S. Geol. Survey, Professional Paper No. 54, 1906.

Tasmania, extensive replacement of an igneous rock, probably under conditions of heat, has taken place. The ore occurs not only in fissure deposit, but also extensively as a replacement of quartz-porphyry.[1] The writer visited this mine in 1904, and at that time large quantities of the igneous rock partly replaced by cassiterite were being mined as ore. Many other similar cases of extensive replacement of igneous rocks under conditions of heat might be mentioned.

Contact Deposits.—The subject of the increased chemical activity of underground waters near igneous rocks, leads up to that large and important class of ore bodies known as contact deposits, lying at or near the contact of the country rock with dikes or other igneous masses. This subject, however, involves more the study of the varied effects of hot igneous rocks on the general geological and chemical conditions of the region, than the direct action of a rock on the character or quantity of ore within it, and though of great scientific and industrial importance, it is beyond the scope of this paper. Suffice it to say here that the occurrence of contact deposits near igneous rocks is probably due in most cases to the fact that the latter are manifestations of past igneous activity, and ore-bearing solutions are generally recognized as being especially abundant and active under such conditions; while in some cases the presence of the ore may be due to a source from the igneous rocks or to the adjoining presence of an easily replaceable rock, or to the fact that the intrusion of the dike has caused fissuring favorable for ore deposition, or to all these causes combined and many others. Such deposits are so numerous as hardly to require illustrations, but it may be said that the silver mines of Leadville and many of the gold mines of Cripple Creek, Col., many of the copper mines of Globe, Clifton and Bisbee in Arizona, the copper mines of Rio Tinto in Spain, and many great mines elsewhere represent contact deposits.

Different Ores in Different Rocks.—The influence of the wall rock of fissures on shoots, already described, relates largely to the effect on the quantity, rather than on the nature of, the ore.

[1] W. von Fircks, *Zeitschrift der deutsch geol. Gesell.*, 1899.

In some places, however, the nature of the ore is affected, and a fissure passing through different rocks may contain one ore where it intersects one rock and another ore where it intersects another rock.

At the Dolcoath mine in Cornwall, England, the ore body was rich in copper near the surface, where it intersected slate, and rich in tin lower down, where it intersected granite. The writer visited this region in 1901, at which time the mining for copper had long ceased, but tin was being actively produced from a depth of over 3,000 feet. The ore of the mine had been copper down to depths ranging from 850 to 1,150 feet, which approximately represented the depth of the slate and granite contact. Below, tin became mixed with the copper, and both metals were contained in the ore for a further depth of from 200 to 250 feet, when the copper gradually disappeared and tin became the only important metal. At Klausen in Austrian Tyrol the veins are rich in silver, lead and zinc where they intersect slates and diorites, and rich in copper where they intersect mica schists and felsite; in the Salzberg Alps some of the veins contain gold where they intersect gneiss and silver where they intersect limestone.[1] In Montgomery and Chester counties, Pennsylvania, where the Triassic sandstone comes in contact with gneiss, copper often occurs in the former rock and lead in the latter.[2]

This influence of country rock on the nature of the ore in a fissure, however, is the rare exception and not the rule. The effect is much more frequently noticeable on the quantity of ore. Moreover an apparent but deceptive relation of the nature of the ore to country rock may sometimes be due to the fact that, in solutions rising in a fissure, as the pressure and heat diminish, certain ores may be deposited at a certain depth and others at another depth according to the conditions of pressure and temperature that permit the precipitation of each.[3] If in this process a

[1] B. von Cotta, "A Treatise on Ore Deposits," Prime's translation, p. 48.
[2] H. D. Rogers and F. A. Genth, quoted by J. D. Whitney, "Metallic Wealth of the United States," pp. 328, 396–398.
[3] A lowering of temperature due to local causes and not necessarily to an approach to the surface, may also have a similar effect in promoting deposition.

certain ore should happen to be deposited where the fissure intersects one rock and another ore where it intersects another rock, the impression might be given that the different rocks had caused the deposition of different ores, whereas the result had been brought about by other causes.

INFLUENCE OF SUPERFICIAL AND DEEP-SEATED ALTERATION.

Constant Changes in Ore Deposits.—An ore deposit is never in a state of complete chemical stability. Even before it is formed, the fissure or other position which it later occupies is the scene of constant changes as a result of the reactions of different solutions on each other. These reactions ultimately result in the deposition of ore, but no sooner is it formed than surface influences, and often deep-seated influences, begin to alter its chemical and physical condition.

Many ore deposits have been derived from hot solutions, often near hot igneous rocks, and after their formation there is a tendency to cool off, a process which may cause them to shrink and become cracked. Moreover, a fissure is a line of weakness and the movement that produced it may be repeated frequently along its course, even after an ore deposit has been formed in it. This is especially true where the fissure has been only partly filled with ore, the rest being more or less filled with selvage. The later fissuring may occur many times in the geological history of an ore deposit and often causes considerable crushing and brecciation in it. Transverse fissuring may also still further shatter the deposit.

These conditions tend to allow surface waters to percolate into the deposit from above, and sometimes subterranean waters to act from below. Moreover, orogenic movements may elevate the region and stimulate erosion, thus exposing new parts of the deposit to alteration; or similar movements may depress the region and subject the deposit to renewed attacks by deep-seated solutions; fresh movements along the fissure may cause renewed shattering, while climatic changes may alter the character of

the surface agencies and give renewed strength to their chemical activity.

Thus the influences to which a deposit is exposed are constantly changing, and no sooner does it show a tendency to chemical stability, than new conditions start fresh chemical activities; and we cannot say that the formation of an ore deposit is ever completed. From the time its formation begins to the time the miner carries away the ore, the deposit is being changed by natural agencies both from above and below. The result is often the formation of ore shoots in places where they did not exist before; or the modification of preëxisting ore shoots either by accretion or diminution of mineral contents. The processes involved in these changes are often similar to those already described in this paper, in other cases they are somewhat different.

Superficial Alteration.—In considering the superficial alteration of ore deposits, we discuss a subject analogous to the surface decay of rocks. The latter, however, involves but a limited number of rock-forming minerals, while the superficial decay of ore deposits involves a great variety of minerals, many of which, under surface influences, give rise to intricate chemical changes. These alterations are the result of the combined action of the atmosphere, surface waters, changes in temperature and the various organic and inorganic materials contained in the air and water. In nature we never deal with perfectly pure water, but different waters contain different ingredients derived from the air and from other materials with which they come in contact. Among the most important of these ingredients are oxygen and carbonic acid, together with numerous other acids, both organic and inorganic, either in a free state or combined with bases.

Surface waters thus charged with various chemical ingredients percolate down into ore deposits and cause great changes in their physical and chemical condition. The oxidation and hydration of certain ingredients, the formation of other new chemical combinations, the leaching of certain ingredients and their deposition below, or their removal altogether from the deposit, and many other effects, are produced. As a result, certain metalliferous

ingredients are sometimes leached from the upper parts of ore deposits and carried down into lower parts, where they are re-

FIG. 12. Longitudinal section through some of the principal mines of the Comstock Lode, Nevada, showing the distribution of ore shoots. Compiled by writer from data in the atlas accompanying Monograph III. of U. S. Geol. Survey, by George F. Becker. The black markings indicate ore. Scale: 1 inch = about 1730 feet.

precipitated by meeting other solutions, or by meeting rocks or minerals which cause deposition, such as calcareous and carbonaceous rocks, masses of sulphides, etc. Hence rich bodies of ore in the form of shoots often collect between the overlying altered part of a deposit and the underlying unaltered part. Such shoots, by their very mode of formation, often tend to have an oblong form, running in the direction of the vein rather than, as most other shoots, running downward in it. On their lower side they often extend out in long projections or tongues, tapering downward until they disappear. The miner's term "fingering out" well expresses this condition.

Ore shoots may be formed higher up in the altered parts of a deposit in cases where certain materials are more resistant to leaching than others, a condition resulting in the concentration *in situ* of the former by the removal of the latter. Thus in a deposit containing copper and gold, surface influences may leach the copper and deposit it below, forming a copper ore shoot, while the gold being less affected remains above, and may develop into a richer deposit than originally, by the removal of the copper and other soluble materials. In the same way the leaching of certain gangue minerals, like calcite or iron pyrites, may cause a concentration of certain metalliferous materials that offer more resistance to leaching.

The depth to which superficial alteration may go is influenced by the topography, the rapidity of erosion, the climate and many other causes, and ranges from a few inches to many hundred feet, perhaps in some cases to several thousand feet. Though most of the ore shoots due to this cause are more or less superficial, yet they are often of immense commercial importance in deposits of both precious and base metals. Many of the great ore shoots of the Comstock lode in Nevada, of the Butte City region of Montana, of the arid regions of Utah, Arizona and New Mexico, many of the iron deposits of Michigan, Wisconsin and Minnesota, and in fact many of the greatest ore bodies of the world owe their existence in part at least to this superficial alteration. As in other influences affecting ore shoots, however.

superficial alteration is not always favorable, and frequently it has an impoverishing effect, but when it enriches the deposit, the results are often wonderfully great.[1]

The mines of Butte City, Mont., were originally started as silver mines, but at a depth of a few hundred feet, copper minerals appeared with the silver, and eventually were found in such enormous quantities as to form the basis of one of the greatest copper mining industries in the world. In this case the ore originally contained copper and silver, but the copper was leached from above, leaving the less soluble silver minerals, and was carried down into the lower parts of the deposits where it enriched the original ore. In a similar manner at the great Mount Morgan mine of Australia, the ore near the surface was rich in gold, but carried only insignificant quantities of copper. Lower down, however, copper became abundant, and the mine is now a producer of both metals. At the time of the visit of the writer to this mine in 1904, it had reached a depth of over 800 feet, and works were just being erected to treat the vast quantities of copper ore that had been found. In this case copper and other materials have been leached from the upper parts of the deposit and the gold left as a concentrated product, often of fabulous richness. Lower down, when the copper appeared, the

[1] This subject of the superficial alteration of ore-deposits is too large to be more than thus briefly mentioned in this general paper, but for its further discussion the reader is referred to:

"The Superficial Alteration of Ore Deposits," by R. A. F. Penrose, Jr., *The Journal of Geology*, Vol. II., 1894, pp. 288–317.

"The Secondary Enrichment of Ore Deposits," by S. F. Emmons, *Trans. Am. Inst. Mng. Eng.*, Vol. XXX., 1901, pp. 177–217.

"The Enrichment of Gold and Silver Veins," by W. H. Weed, *Am. Inst. Mng. Eng.*, Vol. XXX., 1901, pp. 424–448.

"The Iron Ore Deposits of the Lake Superior Region by C. R. Van Hise, 21st Ann. Rept. U. S. Geol. Survey, 1901, pt. 3, pp. 305–434.

"The Formation of Bonanzas in the Upper Portions of Gold Veins," T. A. Rickard, *Trans. Am. Inst. Mng. Eng.*, Vol. XXXI., 1901, pp. 198–220.

"Ore-Deposition and Vein Enrichment by Ascending Hot Waters," by W. H. Weed, *Am. Inst. Mng. Eng.*, Vol. XXXIII., 1903, pp. 747–754.

"Secondary Enrichment in Ore Deposits of Copper," J. F. Kemp, Economic Geology, Vol. I., 1905, pp. 11–25.

gold still remained, but not having been concentrated by the leaching of other materials, the ore was less rich in it.

The manganese deposits of the Batesville region of Arkansas are excellent examples of the concentration of ore as a residual product. Here the ore was once disseminated in limestone, and where surface waters have leached this rock, the less soluble manganese ore has collected in rich pocket in the residual clay left by the limestone.[1]

Deep-seated Alteration.—While superficial influences are altering the upper parts of an ore deposit, deep-seated influences may also be active below. The repeated longitudinal fissuring of a deposit after its formation, as explained on page 124, may afford new channels for the circulation of new ore-bearing solutions from below, and these may profoundly affect the deposit. They may form new ore in new openings, or add to the ore already existing, or perhaps segregate ore formerly disseminated, in all of which cases ore shoots may result. Where large bodies of sulphide ores existed in the original deposit, these may be greatly increased by their precipitating action on the new ore-bearing solutions. The new solutions may sometimes carry different metalliferous materials from the older solutions that formed the original deposit, and may thus form new shoots of different ores. Where an ore body has been intersected transversely by later fissuring, results somewhat similar to those just described as following later longitudinal fissuring may result, but here the action is confined largely to the point of intersection, instead of being spread along the whole fissure as in longitudinal fissuring.

In all these processes, however, the result is not always an increase of value or volume of ore, and, as with most factors which influence ore shoots, there may be no effect at all, or there may be an actual diminution of ore. For instance, when the longitudinal movement along a fissure occurs at only more or less remote intervals, deposition of ore may be increased as just described, but when the movement is very frequent or almost con-

[1] R. A. F. Penrose, Jr., "Manganese; Its Uses, Ores and Occurrence," Geological Survey of Arkansas, Vol. I., 1890, pp. 174–177.

tinuous, it is likely to retard deposition or even to prevent it, for deposition progresses best during intervals of repose after dynamic movements. This may be a cause of the fact observed in some mining regions, though by no means in all, that the ore deposits occur in the smaller fissures and not in those that have been the scenes of the greatest amount of movement.

An excellent case of enrichment from below as the result of repeated movements along ore-bearing fissures, is seen at Goldfield, Nev., where some of the deposits have been shattered by longitudinal fissuring many times and have received new supplies of ore at different periods.[1] Remarkable cases of enrichment after later fissuring, both longitudinal and transverse, are also seen at Butte City, Mont., and many other districts.

SUMMARY.

Ore shoots are bodies of mineral matter which are richer in certain valuable constituents than the enclosing materials. They may be of varying size, continuity, and shape, but their more or less circumscribed character is a distinguishing feature.

Ore shoots are the result of many different chemical and physical influences. These influences sometimes act singly, but generally two or more, often many, act together in producing a given shoot.

Segregation during the cooling of molten magmas in some cases influences the formation of ore shoots.

The occurrence of ore-bearing solutions in local vents influences the position of ore shoots by supplying materials for them in some places and not in others. Thus the channels of fumaroles and hot springs may become the receptacles for shoots.

Gaseous emanations may influence the position of ore shoots by causing precipitation where they occur or by forcing ore-bearing solutions along certain channels.

Structural conditions in a fissure may influence the deposition of ore shoots by offering advantageous openings for deposition.

[1] F. L. Ransome, "The Mining Geology of Goldfield, Nevada," U. S. Geol. Survey, Professional paper No. 66, pp. 196–198.

by forcing the ore-bearing solutions into favorable positions for deposition and in other ways.

Cross fissures may influence the deposition of ore shoots by supplying an additional amount of ore-bearing solution, by shattering the wall rock at the point of intersection, by supplying solutions which cause precipitation from the solutions in the main fissure, by deflecting the solutions in the main fissure to advantageous positions for deposition and in other ways.

The nature of the wall rock of a fissure may influence the deposition of ore shoots to a very marked extent. Its influence is chiefly in affecting the quantity of the ore, but it may also affect the nature of the ore. Its influence is both physical in affording the places for deposition, and chemical, in causing precipitation of ore.

The superficial and deep seated alteration of an ore deposit after its formation may greatly influence the distribution of ore-shoots by the chemical and physical changes that they produce, forming shoots where they did not exist before, or modifying pre-existing shoots either by accretion or diminution of mineral contents.

CONCLUSION.

Many causes tending to produce ore shoots have been mentioned, and their action might have been discussed at greater length, but if one attempted to follow all the modifications and combinations of the processes described, too much detail would be involved for a general paper. Probably the most important and generally observed influences producing ore shoots are those of the wall rock, of intersecting fissures and of local emanations of ore-bearing solutions. These influences, however, rarely act singly; they generally combine with each other or with still different influences in producing ore shoots.

As has been frequently stated before in this paper, however, the influences that may produce ore shoots do not necessarily do so. An ore shoot is the exception and not the rule, and even when apparently the most favorable combination of influences

exists, there may be no ore shoots. Moreover, the causes that have produced a shoot in one region may have no such effect in another region, or in another ore deposit in the same region, or perhaps in another place in the same ore deposit.

In one place, the wide spots in a vein may be the most likely for shoots, in another, the wide spots may be barren and the narrow places rich. In one place, shoots may have a close connection with cross fissures, in another, such fissures may be entirely without influence; in one place, shoots may show a decided preference for certain rocks, in another, the same rocks may seem to discourage shoots. In some places, the action of surface influences causing a superficial enrichment has been a most important factor in developing ore shoots, in others, it has either had no influence, or may even have deteriorated the value of shoots that existed before its influence was felt; in some places later movements along a fissure that has already been filled with ore, have had a marked enriching effect, in others, such movements have had no effect.

More financially disastrous mistakes have probably been made in mining by supposing that because certain conditions hold good in one region, they must hold good in another, than from any other one cause. Every district is a law unto itself in the localization of its ore in shoots, and no district can be properly understood until it has been thoroughly studied *per se*. On the other hand, shoots are not one of those obscure and mysterious phenomena which baffle all efforts at explanation. They are simply the result of natural causes which have been, and are sometimes even yet, active. In almost any district where sufficient mining has been done to permit a thorough examination of the ore deposits, some sort of an idea of the probable cause of the ore shoots should be obtainable.

Though the occurrence of an ore shoot, even under conditions most favorable for its formation, is the exception and not the rule, yet it is worth while to study the causes that produced it, and to look for ore under similar conditions elsewhere. The search in many cases will be fruitless, but another "exception" exists

somewhere, and a knowledge of the conditions under which it may occur is helpful.

Just as the pearl in the oyster is an abnormal segregation resulting in a beautiful gem, so the ore shoot in the earth is an abnormal segregation resulting in precious minerals; just as there are thousands of oysters that contain no pearls to one that does, so there are thousands of apparently favorable receptacles for ore shoots that yet carry none; just as the pearl diver finds it remunerative to hunt for the oyster that may contain his prize, so the miner finds it remunerative to hunt for the spot that may contain his ore shoot; and though the paths of both are strewn with disappointed hopes, yet the possibility of realization leads them on.

ORIGIN OF CERTAIN ADIRONDACK GRAPHITE DEPOSITS.[1]

EDSON S. BASTIN.

The present paper may be regarded as a concrete application of certain general chemical and physical criteria which have been set forth in previous articles by the writer,[2] and by Messrs. F. E. Wright and E. S. Larsen[3] to a very special geological problem; the origin of graphite rocks in the Adirondacks. Although the deposits under consideration are of economic importance, their commercial utilization will not be considered at length in this paper, which deals principally with their characters and the conditions under which they have been formed.

Most of the natural graphite produced in the United States comes from the three states of New York, Pennsylvania and Alabama. Even in these states, however, the graphite industry must be regarded, with one or two notable exceptions, as in an experimental stage. The production is sporadic and of uneven grade, and as a result no steady market has been built up. As much graphite is produced in the electric furnaces at Niagara Falls as is mined in the United States, but even including this the production is not half what our industries demand and an amount valued at somewhat more than the domestic production is imported, mainly from Ceylon and Mexico.

The Adirondack region has for some time been the leading and most regular producing district, largely because of the steady production of one mine at "Graphite" operated by Dixon's

[1] Published with the permission of the director of the U. S. Geological Survey.

[2] Bastin, Edson S., "Chemical Composition as a Criterion in Identifying Metamorphic Sediments," *Jour. of Geol.*, Vol. 17, 1909, pp. 445–472.

[3] Wright, F. E., and Larsen, E. S., "Quartz as a Geologic Thermometer," *Am. Jour. Sci.*, Vol. 27, 1909, pp. 421–447.

American Graphite Company. Other properties which have thus far produced little are of very considerable scientific interest and some are of economic promise. Nearly all the New York deposits which have been worked are located in the eastern and southeastern Adirondack region, in Essex, Warren and Saratoga counties, and the northern part of Washington County. West of the Adirondacks some prospecting has been done in St. Lawrence County. Most of these deposits the writer visited personally during 1909. They are all located within the area of pre-Cambrian metamorphic rocks.

Several brief descriptions of some of the Adirondack deposits, with discussions of origin, have been published; references to the most important of these reports are given at the end of this paper. Citations in parenthesis in the text refer to this bibliography.

All of these graphite deposits appear to the present writer to have resulted from the metamorphism of carbonaceous sediments and to fall naturally into two groups: (1) Those which originated through dynamic (regional) metamorphism alone, and (2) those which have been effected successively by dynamic and by igneous (contact) metamorphism. These two groups will be separately considered.

I. DYNAMICALLY METAMORPHOSED DEPOSITS.

By far the larger number of the graphite deposits and those which are commercially the most important belong to this group. The rocks are quartz-graphite schists containing varying amounts of biotite, feldspar, garnet and other minerals. The graphite, which usually forms from 3 to 10 per cent. by weight of the rock, may be separated by various and usually complicated processes of concentration. The most important principle underlying most of the milling processes is alternate grinding and screening. The grinding pulverizes the quartz, feldspar and other brittle minerals, but does not materially reduce the size of the flexible graphite flakes. The screening separates the pulverized brittle minerals from the larger flakes of graphite. Sup-

plementary processes of separation, which are used in some cases, take advantage of the tendency of flaky minerals such as graphite to float off on a water surface while the massive minerals sink. The type example of the group is the Dixon's mine at "Graphite," west of Lake George.

The Dixon mine is worthy of special description because of its extensive development. It is located at a small settlement known as "Graphite," in the township of Hague, about three miles west of Lake George.[1] The rock utilized is a graphitic quartz-schist which forms bands varying from 3 to 20 feet in thickness, with strike N. 50° E. and average dips of about 20° to the southeast. It outcrops along two nearly parallel belts several hundred yards apart, both of which have been worked, though the southeasternmost working known as the "summer pit" has now been abandoned for many years. In the structure section published by Kemp and Newland ((1) Fig. 4) these two graphitic bands are indicated as repetitions by faulting of the same bed. The writer was not able to test this in the field, but from the close similarity of the two bodies it may well be the case. The workings of the "summer pit" extend for at least 600 feet along the strike but have not been carried far along the dip. The northwesternmost graphitic bed is the one now being worked. The mining is all

[1] In 1898 Mr. Walcott ((2) p. 227) devoted a paragraph to this mine, stating that "The appearance is that of a fossil coal-bed, the alteration having changed the coal to graphite and the sandstone to indurated, garnetiferous, almost quartzitic sandstones." He further describes the graphite bed as "formed of alternating layers of highly graphitic sandy shale, and schist." The rocks of the township of Hague have been briefly described by Kemp and Newland ((1) pp. 537–540). They are principally gneisses of several varieties with small areas of crystalline limestone and of schists of sedimentary origin. The rocks at the Dixon's mine are an example of the latter. The ore is described by these writers as "an impregnation or dissemination of graphite in quartzite," while the bordering rocks are described as quartzites, garnet-sillimanite schist, and hornblende gneiss.

At the time of the writer's visit (April, 1909) twelve years after the observations by Kemp and Newland, the extent of the underground workings had been greatly increased, a large new mill for preliminary concentration erected at the mine and the mill at Hague village dismantled. The concentrate is still hauled by teams eleven miles to a finishing mill at Ticonderoga.

underground and has extended for about 2,000 feet along the dip of the bed, the deepest parts of the mine being about 200 or 250 feet below the surface. Because of the gentle inclination of the graphitic bed no tunnels or shafts need be driven through barren rock; practically all of the excavation is in material that can be milled, the roof being supported by timbering and occasional pillars of ore. The mining process therefore bears more resemblance to coal mining than to most lode mining. The graphitic rock is extremely hard and tough, and compressed air drills are used. The blocks blasted down are broken with sledges into pieces eight or ten inches in diameter, loaded onto cars and hauled by electric locomotives to the nearby mill. The average daily output of the mine is 160–180 tons. The milling process is kept secret.

The graphitic rock utilized is a medium-grained quartz-graphite schist, dark silver-gray when fresh, but stained yellow and brown when weathered. An analysis of a composite sample taken by the writer from the bins at the mill and designed to be roughly representative of the general run of the material used showed[1] 6.25 per cent. of graphitic carbon. The graphite content probably varies in different parts of the deposit from about 3 per cent. to as much as 10 per cent. of graphite. The concentrates from the mill are said to average about 3 per cent. by weight of the rock mined.

A sample of the graphitic rock examined under the microscope showed quartz as its dominant mineral. This occurs in irregularly interlocking grains, many of which show undulatory extinction. Muscovite occurs as aggregates of minute shreds forming irregular bands and patches. Some of these probably represent altered feldspar grains. Apatite is abundant in small prisms with more or less rounded outlines. There is an occasional small plate of biotite. The graphite forms flakes of an average length of about 0.9 mm. and an average thickness of about 0.09 mm. The longest flake in the section was 2.8 mm., and a few were as much as 0.2 mm. in thickness. Cross sections of the graphite

[1] Analyzed in the laboratory of the U. S. Geological Survey.

flakes show them to possess very ragged and irregular surfaces. Graphitic schist from a neighboring prospect known as Faxon's mine, probably a continuation of one of the Dixon graphitic beds, differs from the above mainly in showing an occasional grain of plagioclase feldspar and microcline.

The habit of the rock is decidedly schistose, due to a tendency for the quartz grains to be more or less elongate in the same direction and for many of the graphite plates to be oriented parallel. Plate I. is a microphotograph of the graphitic schist taken from the Dixon mill, the black flakes being graphite.

The immediate wall rock is in many places a gneiss with pink garnets up to one half inch in diameter in a matrix composed of interlocking grains of brown biotite, feldspar and quartz, with a few scattered plates of graphite. In other places, as described and figured by Kemp and Newlands ((1) Plate X.) the wall rock is composed almost wholly of garnet and sillimanite. Another dark-gray schistose rock which is locally interbedded with the ore, but which is discarded in mining, is seen under the microscope to consist wholly of quartz, plagioclase feldspar, and greenish-brown biotite, with no graphite. At the Faxon prospects bands of crystalline limestone containing grains of augite, quartz and some scapolite are interbedded with the garnet-gneiss.

As regards genesis there can be little doubt that the graphitic schist and its associated rocks are of sedimentary origin and they were so regarded by both Walcott and Kemp. The evidences of sedimentary origin are found (1) in the highly quartzose, non-feldspathic character of most of the graphitic rock; (2) in the evenly and highly garnetiferous character of much of the wall-rock; (3) in the persistence of the graphitic schists and associated garnetiferous gneisses with fairly uniform trend, width and character for considerable distances; (4) in the presence locally of interbedded masses of crystalline limestone; and (5) in the fairly even dissemination of the graphite through the workable schist. The relatively small proportion which the graphite bears to the whole mass of the rock (usually 5 to 10 per cent.) makes it difficult to interpret the graphitic bed as anything akin to a

metamorphosed coal bed. Moreover, practically all of the graphite deposits known to be formed through the metamorphism of coal beds are of the amorphous variety even when associated with wall-rocks which are crystalline schists. The writer is in closer accord with Kemp's view that the original rock was a bituminous shale. It seems most probable that the deposits represent carbonaceous sandstones, locally clayey, interbedded with only slightly carbonaceous impure sandstones and with small amounts of limestone, all of which have been completely recrystallized with the development of a schistose structure and the conversion of the original carbonaceous material into graphite through the usual processes of dynamic metamorphism.

Graphitic schist very similar to that at the Dixon's mine has been developed two and one fourth miles west of Porter Corners, Greenfield Township, Saratoga County. The workable ore bed is at least 25 feet thick. It differs from the Dixon graphitic schists mainly in containing feldspar (orthoclase and plagioclase) in nearly equal abundance with quartz. Exposures of the wall-rock are rare at the mine, but one half mile north of this mine graphitic schists of nearly identical character are interbedded with thick beds of quartzite and are probably therefore of metasedimentary origin.

The graphite-bearing rocks which have been experimentally exploited at three mines in the town of Dresden about five miles northwest of Whitehall are also schists. The best exposures are at the mine of the American Graphite Company where a thickness of at least 25 feet of graphitic schist is exposed. The analysis[1] of a composite sample selected by the writer from various parts of the pit is given below.

SiO_2	65.10
Al_2O_3	9.15
Fe_2O_3	4.68
FeO	3.09
MgO	2.21
CaO	1.71
Na_2O	.24

[1] Analysis made by Geo. Steiger in the laboratory of the U. S. Geological Survey.

K_2O	2.32
H_2O-	.50
H_2O+	2.33
TiO_2	.96
CO_2	none
P_2O_5	.74
S	3.26
MnO	.03
C	5.29[1]
Total	101.61
Less O[2]	1.63
	99.98

It is seen to contain 5.29 per cent. of graphitic carbon. The rock is a dark silver-gray, well-foliated schist. A thin section when examined under the microscope shows quartz as the principal constituent. Areas which are largely aggregates of small muscovite shreds probably represent altered feldspar grains. Brown biotite, magnetite, pyrite and graphite are the other abundant constituents. Zoisite is subordinate. The pyrite is mainly confined to a few bands parallel to the schistosity. The graphite occurs in flakes from .015 mm. to .27 mm. thick and up to 1.3 mm. long, the average length not exceeding .75 mm. in the thin section studied. It is closely associated with the biotite, the two minerals frequently being interleaved. The subparallel elongation of the biotite and graphite flakes gives the rock its schistose structure.

In an article published in 1909[3] the writer discussed quantitatively the value of certain chemical relationships as criteria of the sedimentary versus the igneous origin of certain schists. The conclusions there reached may be summarized as follows: In fresh foliated rocks, (1) dominance of MgO over CaO is strongly indicative of sedimentary origin; (2) dominance of K_2O over Na_2O is of lesser critical value, but is nevertheless suggestive of sedimentary origin; (3) the double relationship of dominance both of MgO over CaO and of K_2O over Na_2O affords very

[1] Graphite.

[2] Correction for iron in pyrite determined as FeO.

[3] Bastin, Edson S., "Chemical Composition as a Criterion in Identifying Metamorphosed Sediments," *Jour. of Geol.*, Vol. 17, 1909, pp. 445–472.

strong evidence of sedimentary origin; (4) the presence of any considerable excess of Al_2O_3 in the analysis over and above the 1:1 ratio necessary to satisfy the lime and alkalies, is also suggestive of sedimentary origin; (5) high silica content may be indicative of sedimentary origin when supported by other criteria. When three or all of the above relationships hold good, the evidence of sedimentary origin may be regarded as practically conclusive.

In the schist analysis given above MgO dominates over CaO and K_2O over Na_2O. The percentage of Al_2O_3 is not excessive but the silica content is very notably greater than in the most closely related igneous rock of Washington's tables of analyses.[1] The chemical analysis therefore furnishes in the writer's opinion almost conclusive evidence that this schist is of sedimentary rather than of igneous origin. The original rock was probably a somewhat carbonaceous sandy shale.

At the Bly or Jumbo mine on Bear Pond Mountain in the town of Ticonderoga the rocks are quartz-mica schists with fairly regular east and west strike and nearly vertical dip. Within these masses occur at least two broad bands which are graphitic. One attains locally a width of at least 100 feet and the other a width of 40 feet. Both are traceable for long distances along the strike and the quantity of graphitic rock present is undoubtedly large.

Three samples of graphitic schist from different prospect pits on this property were examined under the microscope and were found to be composed of interlocking grains of quartz and feldspar in nearly equal abundance, with much biotite and graphite and an occasional grain of epidote. The feldspar is in part orthoclase and in part andesine, and many of the grains are clouded with alteration products. The biotite is in part altered to chlorite.

[1] When the norm of this schist is calculated it is found to fall in Class II. of the Quantitative System of Cross, Iddings, Pirsson and Washington, with 49.56 per cent. of quartz in the norm. Among the igneous rocks of Class II. tabulated in Washington's Tables (Proffesional Paper No. 14, U. S. Geol. Survey) only one rock shows over 40 per cent. of quartz in the norm and only fourteen show over 30 per cent. out of the 719 tabulated.

The rock differs from that mined at " Graphite " in being more feldspathic and biotitic and particularly in the fact that nearly all the graphite present is either intergrown with the biotite or closely associated with it. Most of the graphite plates are bordered on both sides by biotite and lie between the biotite laminæ as between leaves of a book. Thus biotite crystals 0.15 to 0.45 millimeter thick may inclose graphite flakes of about one tenth of this thickness. This feature is illustrated in Plate II. and must increase greatly the difficulty of concentration. Analyses of four samples of graphitic schist from various pits on this property made for the owners are reported to run 6.4, 6.6, 6.2 and 8.8 per cent. of graphitic carbon. The subparallel orientation of the biotite and graphite flakes give the rock its schistose structure.

The geology of this region has been mapped by Miss Ida H. Ogilvie (4) who regards the schists of Bear Pond Mountain as of sedimentary origin. Miss Ogilvie's view, in regard to the origin of the disseminated graphite deposits, with which the present writer is in full accord, is as follows:

> The widespread dissemination of graphite scales in sedimentary limestone and quartzite can best be explained on the organic hypothesis. There seems no possibility of any origin but that of a metamorphic product from some original constituent of the rock, and regional metamorphism is the only process by which it can reasonably be supposed to have been formed. It seems most probable that the original limestone and sandstone were heavily charged with organic material which in the pre-Potsdam period of metamorphism was competely reduced and in some part volatilized.

Summary.—In summation the type of low grade, disseminated graphite deposits of the Adirondack region appear from their field relations and their chemical composition to be carbonaceous sediments of the sand-clay type which have been regionally metamorphosed with the development of schistose structures and the conversion of the amorphous carbon into graphite. The original state in which the carbon existed, whether as bitumen, plant remains, etc., is unknown. Graphitic rocks of this type differ among themselves principally in the amount of feldspar

and biotite present and in the size and abundance of the graphite flakes. Large size in the graphite flakes and scarcity of biotite especially in parallel growth with the graphite add greatly to the ease and cheapness of concentration.

II. DEPOSITS FORMED BY SUCCESSIVE DYNAMIC AND IGNEOUS METAMORPHISM.

Two somewhat dissimilar occurrences of graphitic deposits of this type are known to the writer in the Adirondack region.

The first is the mine of the Crown Point Graphite Company[1] about seven and one half miles southwest of Crown Point Centre and just north of Chilson Lake. The mine lies within the area of the Paradox Lake Quadrangle (4) mapped by Miss Ogilvie. According to this map the mine lies close to the contact of a large area of pre-Cambrian gneissic granite with hornblende gneisses and interbedded schists regarded as of sedimentary origin.

The common rocks at the mine are crystalline limestones, pyroxene-biotite schists and granites. The crystalline limestone is nearly everywhere graphitic and is the rock utilized. It occurs in several nearly parallel bands. The one now being worked strikes N. 65–70° E., and dips 55–60° to the south. Its width varies from 3 to 7 feet and it is traceable along its strike for over 1,000 feet. A second bed of graphitic limestone occurs about 375 feet south of the main bed, but is apparently narrower and is not traceable far along its strike. A few other small and unimportant lenses also occur.

The best graphitic rock from this mine is made up almost entirely of calcite grains and plates of graphite with a few scattered grains of augite. Much of the rock utilized, however, is a darker gray in color due to the presence of more augite. Under the microscope this type is found to consist of interlocking grains

[1] The deposit in April, 1909, had been developed by an inclined shaft about 72 feet deeep from which the miners had drifted eastward and raised the surface again about 150 feet from the shaft. A mill for preliminary dry concentration is located at the mine and a finishing mill at Crown Point Centre. The ore being calcareous, is soft and easy-milling.

of calcite averaging about 2 mm. in diameter, of green augite partly altered to chlorite and of graphite plates. Most of the latter range from 0.9 to 3 mm. in length and from 0.15 to 0.3 mm. thick and are therefore several times larger than the graphite flakes of the Dixon's rock from "Graphite." The rock shows very little tendency towards a schistose structure and the graphite plates are oriented in every direction. A faint banding is due to the greater abundance of augite in certain layers than in others. Little or no mica is present. Plate III. is a microphotograph of this rock. A composite sample of the graphitic rock selected by the writer to show the average run of the material now being mined analyzed[1] 2.97 per cent. of graphitic carbon.

Rocks in which narrow gray bands alternate with bands which are dark-green to brownish-black are interbanded with the workable layers. Under the microscope the dark bands are seen to consist largely of augite with occasional grains of hornblende and chalcopyrite. Along some foliæ biotite flakes are abundant. The lighter bands were probably originally composed largely of scapolite grains which are now altered to aggregates of small muscovite shreds. Certain phases show quartz and flakes of graphite in both the lighter and darker bands. Certain phases of the schist associated with the workable rock become coarsely crystalline, showing dark-brown pyroxene crystals up to 1 inch across, crystals of calcite ½ to 1 inch across, pyrrhotite grains up to ½ inch or so in diameter and graphite plates up to ½ inch across. These are the largest graphite crystals found at this locality.

Granite occurs near the graphitic rocks in dikes which are mainly parallel to them in trend but which here and there cut across the limestone and associated schists. The granite is therefore distinctly intrusive. Narrow tongues of garnet-bearing aplite (mainly quartz and microcline) which are interbanded with the schists and limestone are probably offshoots from the larger granite dikes. No graphite, calcite or pyroxene was observed either in the larger granite dikes or in the aplitic offshoots.

[1] Analyzed in the laboratory of the U. S. Geological Survey.

The high lime content of the graphitic rock at this mine is regarded as sufficient proof of its own sedimentary origin, and as indicating a similar origin for the pyroxenic and biotitic schists with which it is most intimately interbanded. Like the other pre-Cambrian sediments of this region these rocks were unquestionably subjected to dynamic metamorphism with recrystallization and the development of more or less schistose structure. Later they were intruded and further metamorphosed by dikes of granite usually parallel to but locally cutting across their trend. The graphite is believed to represent an original carbonaceous constituent of the limestones converted to graphite by dynamic metamorphism and later recrystallized wholly or in part through the igneous metamorphic effects of the granite. The associated pyroxene-scapolite-biotite schists are believed to represent the effects of igneous metamorphism on the more argillaceous portions of the sedimentary series. The argument for such a genesis is the same for this deposit and for the one next to be described, and will be deferred to a later page.

The last graphite property to be described is of no present commercial importance, but from the scientific standpoint is the most interesting one known to the writer. The mine is located on Lead Hill about three miles northwest of Ticonderoga.[1] The writer visited the property in April and again in October, 1909. Exposures are interrupted in the vicinity of the workings, though sufficient to reveal the principal geologic relationships.

The most abundant rocks are granitic and include granite-gneiss, pegmatite and pegmatitic granite, all of variable texture. A common type of granitic rock exposed some yards away from any graphitic exposures is normally millimeter-grained, subequigranular, and shows microcline, oligoclase, quartz and biotite as its principal minerals. Garnet is subordinate and forms pink

[1] This mine has now been idle for many years. It is owned by Dixon's American Graphite Company and has been worked in a small way by lessees. The workings consist of numerous open pits, the largest about 20 by 40 feet and 20 feet deep, scattered over an area of several acres. In addition a tunnel about 200 feet long has been driven, from the end of which raises from irregular stops connect with the surface.

blotches scattered through the rock. Locally in irregular zones this granite becomes coarser and of uneven fabric, *i. e.*, becomes pegmatitic. In places these granitic rocks show rude flow structure and become gneisses. The granitic rocks exposed near or in contact with the graphitic rocks are nearly all pegmatitic in their texture. Most of them are finely so, the mineral grains rarely exceeding an inch or two in diameter. At the largest of the open pits, however, the pegmatite is coarse-grained and consists largely of clear to smoky quartz with some feldspar in certain parts. Some other pegmatite ledges in the vicinity show feldspars 8 to 10 inches in diameter.

The rocks with which these granitic types are associated include (1) crystalline limestones, (2) quartz-mica schists, (3) hornblende schists and (4) pyroxene-scapolite rocks and related types. The crystalline limestones are present only as a few bands seldom over 3 to 4 feet thick, which pinch and swell and are frequently cut off by intrusions of pegmatitic granite. The limestone wherever found is coarsely crystalline and graphitic, and resembles in general that at the Crown Point Graphite Company's mine, previously described. At Lead Hill, however, it is the pyroxene-scapolite rocks later to be described, and not the graphitic limestones, that have been worked. Near the pegmatite some apatite and much augite are often developed in the limestone, the latter largely in bands which perhaps represent original bedding-planes. Near some of the pits schists of even foliation are exposed which consist largely of quartz with some muscovite and biotite and an occasional grain of pyrite. With little doubt they represent metamorphosed impure sandstones. Interbanded with the quartz-schists are very dark-colored schists dominantly of hornblende and plagioclase with subordinate quartz and augite and accessory magnetite and pyrite. An analysis of this rock shows that it is similar chemically to numerous basalts, gabbros, diabases and diorites of the Sub-rang Auvergnose. It may be the metamorphic equivalent of a basic rock intruded into the sediments or may represent a ferruginous arkose forming a part of the sedimentary series itself. A single

dark-green dike, aphanitic and probably diabasic, cuts the pegmatite at one point.

The rocks of unusual character which have been mined as sources of graphite at this locality occur between the pegmatite and the limestones and schists described above and are probably of igneous (contact) metamorphic origin. They are in complete crystallographic continuity with the pegmatite on the one hand and the limestone and schists on the other, the vague and irregular contacts being from a few feet to several yards in width. The principal minerals of the contact zones are dark-green to purplish-brown augite, scapolite and graphite; quartz and calcite are subordinate, and apatite, biotite, pyrite, pyrrhotite, titanite and vesuvianite accessory. The dimensions of these minerals vary from minute up to diameters of six inches for some of the calcite and augite crystals, 2 inches for some scapolite crystals, and 1½ inches for some biotite plates and titanite crystals. The coarsest crystallizations noted are in the underground workings along the exact pegmatite contact. The graphite occurs in flakes usually less than ½ inch across but locally as much as 1½ inches in diameter penetrating the other minerals in all directions. Large portions of the contact zone are composed almost wholly of a granular aggregate of augite grains from 1/16 to ⅛ of an inch in diameter, but the commonest phase consists of augite, scapolite and graphite. Limited portions consist largely of graphite, of graphite and scapolite, or of graphite and augite. In some places a banding which may possibly be a remnant of original bedding shows itself in an alternation of layers largely augite with others largely scapolite. The scapolite, as shown by the low soda content in the rock analysis given below, must belong to the Meionite variety (largely $Ca_4Al_6Si_6O_{25}$ with little if any of the isomorphous compound $Na_4Al_3Si_9O_{24}Cl$). In many hand specimens perfect crystal continuity may be traced between scapolite and calcite. Both minerals frequently form a matrix enclosing augite grains.

A composite sample of the augite-scapolite-graphite rock collected by the writer and analyzed by Mr. Geo. Steiger in the laboratory of the U. S. Geological Survey is as follows:

SiO_2	47.91
Al_2O_3	6.32
Fe_2O_3	.33
FeO	3.11
MgO	11.86
CaO	22.88
Na_2O	.40
K_2O	.46
H_2O-	.10
H_2O+	.96
TiO_2	.44
CO_2	.95
P_2O_5	.25
S	.05
MnO	.08
C	4.00[1]
Total	100.10
Less O[2]	.02
	100.08

The assemblage of minerals making up the rocks of the contact zone above described is regarded as sufficient proof of their metamorphic origin, vesuvianite and scapolite in particular being largely confined to contact metamorphic deposits.[3] It may be noted, however, in passing that if we disregard the graphite content and compute position of the rock in the Quantitative Classification[4] of Igneous Rocks, its composition is not far different from that of certain basic igneous rocks. In such a case mode of occurrence and mineral composition rather than chemical composition must serve as criteria of genesis. Both of the former point to an origin by igneous metamorphism. The abundance of the aluminous lime silicate, scapolite, and of the lime-magnesia-iron silicate augite; as well as the interbanding

[1] Graphite.

[2] Deduction for pyrite determined as FeO.

[3] Mr. Frank Calkins has reported the occurrence of scapolite in aplitic dikes in the Philipsburg region in western Montana (*Science*, Vol. 29, 1909, pp. 946–47) and Adams and Barlow (*Proc. Roy. Soc. Canada*, Vol. 2, 3d series, 1908, p. 9) have reported its presence in certain nephelite syenites of eastern Ontario. In both cases the writers postulate absorption of limestone in explanation of the unusual composition of the rocks concerned.

[4] Cross, Iddings, Pirsson and Washington, "Quantitative Classification of Igneous Rocks," 1903.

locally observed of the pyroxene-scapolite rocks with more or less pure crystalline limestone, suggest that the material from which the graphite rock was derived was a clayey and carbonaceous magnesian limestone. The chemical analysis, though not proving this view, is accordant with it.

While most of the material of the pyroxene-scapolite contact rocks appears to have been derived from the sedimentary series, some was probably contributed by the intrusive pegmatite and conversely the pegmatite itself suffered slight changes in composition near the contacts. These are minor, but manifest themselves in the presence of scattered crystals of pyroxene, scapolite and graphite in those portions of the pegmatite which are closest to the intruded rock. The endomorphic effects were very slight, however, as compared with the exomorphic.

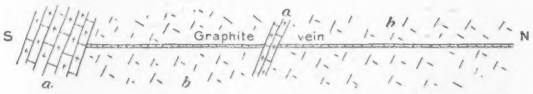

FIG. 13. Diagram showing graphite vein cutting pegmatite (*b*) but terminating abruptly against bands of graphitic crystalline limestone (*a*). Lead Hill, Ticonderoga.

In addition to the mode of occurrence described above, graphite is found at this locality in distinct veins or fissure fillings. These are all nearly vertical and of nearly parallel northerly trend. As many as eight or ten of these have been worked, some for a length of 100 feet. Some of these veins traverse the schists and pyroxene-scapolite rocks but end abruptly against a cross-cutting mass of pegmatite; others traverse pyroxene-scapolite rock and pegmatite, indiscriminately. None so far as observed traverse the limestone. In one pit the relations shown in Fig. 13 below were observed, the vein terminating abruptly against a cross-band of graphitic limestone, though continued again in the pegmatite beyond it (Fig. 13). In a single instance a graphite vein in pegmatite was continued as a barren tight fracture into the adjacent limestone.

The veins themselves are from ¼ inch to 2 inches in width and

consist almost wholly of graphite in flakes which are set approximately at right angles to the walls. Locally they contain small amounts of calcite, augite, quartz or scapolite with the graphite. The veins as a rule show sharper walls in the pegmatite than in the pyroxene-scapolite rocks.

From the descriptions which have been given it will be seen that the deposit at the Crown Point Graphite Company's mine and that at Lead Hill are characterized by very similar rocks

FIG. 14. Microphotograph of graphitic schist from the Dixon's mine at "Graphite," Township of Hague. Magnified about 40 diameters. The black portions are graphite flakes; the remainder of the rock is largely quartz.

and minerals. At both localities we have a series of metamorphic rocks whose original sedimentary character is shown by the presence of quartz schists and considerable masses of crystalline limestone. At both localities these have been dynamically metamorphosed with the development of more or less perfect foliated structures. At both localities the meta-sedimentary schists and crystalline limestones were later intruded by masses of granite and pegmatite with resulting igneous metamorphism.

The igneous metamorphism produced much more marked effects at Lead Hill than at the Crown Point mine. At both localities the granite and pegmatite carry practically no graphite, augite, etc., except in the immediate vicinity of the wall rocks and even there the amount of such minerals is small.

As regards the origin of the graphite, its scarcity in the granitic rocks can not be regarded as proof that it was not

FIG. 15. Microphotograph of graphitic schist from the Bly mine at Bear Pond Mountain, Ticonderoga. Magnified about 40 diameters. The mottled gray areas are largely altered feldspar; the even white to gray areas are quartz; the foliated mineral is biotite, between the leaves of which occur thin plates of graphite which appear black in the photograph.

derived therefrom, since instances are numerous of ore deposits formed through exomorphous effects of igneous rocks when the igneous rocks themselves do not show important amounts of the ore minerals. On the other hand, the fairly even dissemination

of the graphite through the limestone at the Crown Point mine and in particular the occurrence of graphitic schists such as those at "Graphite" and Bear Pond Mountain in other portions of the pre-Cambrian of this general region which are not associated with igneous rocks makes it much more probable that the graphite represents an original carbonaceous constituent of the sediments. This carbon was probably graphitized during the dynamic metamorphism which gave these sediments their foliated structure and later rearranged with the formation of much larger flakes and the development of an association of typical igneous metamorphic minerals, at the time the granitic rocks were intruded. The veins of graphite at Lead Hill appear to have been formed during the latest stages of the igneous metamorphism when certain of the granitic intrusions had become sufficiently rigid for the formation of fractures in them but before recrystallization had ceased in the limestone. This is evidenced by the abrupt termination of the veins against the limestone illustrated in Fig. 1. The graphite was presumably carried in gaseous solution from the sedimentary rocks into the fracture planes and there deposited.

Some conception of the temperature conditions at the time of this contact metamorphism can be gained by applying certain tests devised by Messrs. Wright and Larsen in a research of unusual geologic interest.[1] The studies of these writers and of earlier observers have shown that at about 575° C. there is a sudden change from one form of crystal symmetry to another. Below 575° quartz, which has been called α quartz, crystallizes in the trapezohedral-tetartohedral division of the hexagonal system, while the β form developed above 575° crystallizes in the trapezohedral-hemihedral division of the same system. Since the α and β quartz have practically the same density, pressure probably has little effect on the temperature of inversion. Wright and Larsen have shown that the α and β forms may be distinguished by certain optical tests for[2] "if at any time in its history a par-

[1] Wright, F. E., and Larsen, E. S., "Quartz as a Geologic Thermometer," *Amer. Jour. Sci.*, Vol. 28, June, 1909, pp. 423–447.

[2] *Ibid.*, p. 425.

ticular piece of quartz has passed the inversion point and been heated above 575° C., it bears ever afterwards marks potentially present which on proper treatment can be made to appear just as an exposed photographic plate can be distinguished at once from an unexposed plate on immersion in a proper developer, although before development both plates may be identical in appearance." To quote these writers further:[1]

> Briefly stated, the four criteria which can be used to distinguish, at ordinary temperatures, quartz which was formed above 575° from quartz which has never been heated to that temperature, are: (1) Crystal form, if crystals be available, the presence of trigonal trapezohedrons and other evidence of tetartohedrism, irregular development of the rhombs and the like, being indicative of the α form. (2) Character of twinning, as shown by etch figures on the basal pinacoid. In the α form, which crystallized from solutions at comparatively low temperatures, the twinning is usually regular and sharply marked, while in quartz plates originally of the β form and now α by virtue of inversion in the solid state, the lines are usually irregular, and the twinning patches are small and bear no relation to the outer form of the crystal. (3) Intergrowths of right- and left-handed quartzes are more frequent and more regular in boundary lines in the α than in the β form. (4) Plates of originally β quartz but now α quartz by inversion show the effect of the inversion by the shattering which should be most evident on large plates. Into all these criteria an element of probability enters, and in testing quartz plates, with this end in view, a number of plates should be examined to strengthen the validity of the inferences drawn.

With the kind tuition of Mr. Larsen I prepared and studied a suite of eight sections of quartz from the contact zone at the Lead Hill mine. This quartz was penetrated in the most irregular manner by flakes of graphite oriented in all directions and enclosed numerous crystals of augite. There can be no doubt that the three minerals crystallized contemporaneously. Quartz of similar appearance in other parts of the contact zone is intergrown with calcite titanite and scapolite. The results of the tests showed beyond reasonable doubt that the quartz belonged to the α variety formed below 575° C. Many of the masses are transparent and free from the shattering characteristic of β quartz.

[1] *Ibid.*, p. 438.

Twinning as shown by the etch figures on basal sections is regular when present, while some sections show none whatever. The right- and left-handed intergrowths present show regular boundaries. The quartz tested came from two widely separated parts of the contact zone but all the sections exhibited similar properties.

FIG. 16. Graphitic crystalline limestone from the mine of Crown Point Graphite Company, near Chilson Lake. Magnified about 40 diameters. The most abundant mineral is calcite, *C*. *A* = grains of augite. The black areas are graphite flakes.

If the criteria applied are trustworthy, as they appear to be, they indicate that the quartz graphite and augite of this igneous metamorphic zone crystallized below 575° C. and that the closely associated scapolite, calcite, apatite, pyrite, pyrrhotite, titanite and biotite probably crystallized at similar temperatures. These results are in harmony with those obtained by Wright and Larsen

on the quartzes of certain pegmatites which showed that these bodies crystallized at temperatures not far from the inversion point of 575° C. These temperatures are in marked contrast with those at which graphite is artificially produced in the electric furnace (certainly over 2000° C.) and serve to emphasize the importance which the time element and the nature of the other substances present may have upon the crystallization of natural minerals.

The graphite of Lead Hill has been described by one writer as occurring in pegmatite ((3) p. 512). A small amount of it *is* in the pegmatite but most of it is in a contact metamorphic zone. It may not be inappropriate, however, to emphasize here the probability that certain deposits showing pegmatitic textures may partake to some extent of the nature of contact metamorphic deposits since pegmatite solutions emanating from igneous masses may receive accessions of material from the wall rocks through which they pass.

Summary.—The discussion of the Adirondack graphite rocks of dynamic metamorphic origin has already been summarized on page —. The deposit worked by the Crown Point Graphite Company and that at Lead Hill are believed to be dynamically metamorphosed carbonaceous sediments which later were further metamorphosed by the intrusion of granitic rocks. A study of quartz from the contact metamorphic zone at Lead Hill indicates that the temperatures at which the graphite and associated minerals crystallized probably did not exceed 575° C.

1. **Kemp, J. F., and Newland, D. H.**
1897. Preliminary report on the geology of Washington, Warren, and parts of Essex and Hamilton Counties, N. Y. 51st Ann. Rept., N. Y. State Mus., vol. 2, pp. 537–540.

Describes the rocks of Hague as gneisses of several varieties mostly striking northwest. Crystalline limestone occurs at two points and pre-Cambrian sedimentary schists at several localities. The best exposures of such schists are at the mine at "Graphite." "The graphite deposit is an impregnation or dissemination of graphite in quartzite." Microphotographs of the garnet-sillimanite wall-rock. The preliminary concentration at this mine is

by California stamps and buddles. The further concentration process at the finishing mill at Ticonderoga is secret. A map and structure section of the locality forms Fig. 4.

2. Walcott, C. D.

1899. Pre-Cambrian fossiliferous formations. *Geol. Soc. Amer. Bull.*, Vol. 10, p. 227.

Devotes one paragraph to the mine at "Graphite" in Hague, Essex County, N. Y. States: "The appearance (of this graphitic bed) is that of a fossil coal-bed, the alteration having changed the coal to graphite and the sandstone to indurated, garnetiferous, almost quartzitic sandstones." Reproduces photograph of graphitic bed (Plate 22).

3. Kemp, J. F.

1903. Graphite in the eastern Adirondacks, New York. Bull. U. S. Geol. Survey, No. 225, pp. 512–514.

Deposits confined to Algonkian rocks and occur in (1) pegmatite veins, (2) veinlets of graphite, (3) quartzites, (4) crystalline limestones with associated gneissoid strata. Deposit of Chilson Hill near Ticonderoga referred to pegmatite class and briefly described. Graphitic veinlets at Split Rock on Lake Champlain described. Graphitic quartzites of Hague described. Milling processes described. Other graphitic quartzite localities mentioned. The graphitic quartzites are believed to be metamorphosed bituminous shales. Describes occurrence of graphite in crystalline limestone. Discusses uses of graphite briefly.

4. Ogilvie, Ida H.

1904. Geology of the Paradox Lake Quadrangle, New York. Bull. 96, New York State Museum.

Describes sillimanite gneiss associated with graphitic rock at "Graphite" (6 lines, p. 495). Describes mode of occurrence of graphite at "Graphite," Warren County, and at Rock Pond, Essex County. Cites Weinschenk on origin of graphite (10 lines). "The Adirondack graphite is plainly of two kinds; that present as an accessory constituent of the limestone and quartzite, and that occurring in a secondary position along fault lines." Former is regarded as original carbonaceous constituent of sediments, graphitized by dynamic metamorphism. The latter represents a part of the graphite which was volatilized during the same metamorphism, transported somewhat, and later sublimed along fracture planes (pp. 503–505).

5. **Newland, D. H.**

The mining and quarry industry of New York State. Bulletins Nos. 102, 112, 426, and 451. New York State Museum.

1905. Bull 102, pp. 73–78. Republishes most of Kemp. Bull. 225. Briefly describes mines at "Graphite" in Warren County, at Rock Pond and Mineville in Essex County, and in Dresden, in Washington County. Milling methods. Statistics of production for 1905.

1906. Bull. 112, pp. 26–27. Progress of industry. Statistics of production for 1906.

1907. Bull. 426, pp. 29–31. Briefly describes mines near Conklingville, in Saratoga County, and near Rossie in St. Lawrence County. Discusses difficulty of concentration and effects of presence of mica and of size of graphite flakes on concentration. Progress of industry and statistics of production in 1907.

1908. Bull. 451, pp. 28–29. Progress of industry and statistics of production for 1908. Brief description of mine near Chilson Lake, Essex County.

NOTES ON TUNGSTEN MINERALS FROM MONTANA.

ALEXANDER N. WINCHELL.

The demand for tungsten ores shows no signs of decreasing. Ores carrying sixty per cent. of tungstic oxide sold for less than $300 per ton during some months of 1908 and 1909; at present such ores sell for more than $400 per ton. Tungsten ores are rather widely distributed in nature, and concentration of the ores into commercial deposits has occurred at many places. But these deposits seem to be irregular, and lacking in continuity, so that they are usually very quickly exhausted. It is to be hoped that larger deposits will be found, which will ensure a continuous and steady supply to the market. For this purpose a wider knowledge of the physical characters and modes of occurrence of tungsten minerals is important. As partially supplying this need, it is intended to give here a description of the characters and occurrence of those tungsten minerals which have served as ores in Montana. Incidentally, the development of cigar-shaped lenses of quartz from a quartz vein will be described.

The chief minerals which serve as ores of tungsten are wolframite, which is a tungstate of iron with some manganese, and scheelite, which is a tungstate of calcium. Hübnerite and tungstite serve as minor sources of supply. Scheelite and hübnerite have been found in commercial quantities in Montana; wolframite and tungstite probably occur, at least in small quantities. Tungsten ores have been mined at two localities, namely, Jardine and Butte.

Jardine is located in the southern part of Park County only about two miles north of the northern boundary of Yellowstone National Park. In fact white terraces of travertine at Hot Springs are visible from the site of the mine which created Jardine. The mine and town are about five miles northeast of

the terminus (Gardiner) of the Yellowstone Park branch of the Northern Pacific Railroad. The mine is located at an elevation of about 7,000 feet above sea level on the lower slopes of a mountain just east of Bear Gulch. The mine was opened as a gold property, and gold placer mining in the lower parts of Bear Gulch has been carried on for at least twenty years. The country rock of the region is described by Iddings and Weed[1] as consisting of mica schists and phillites, but no rock with slaty cleavage or megascopic schistosity occurs in or near the mine, except locally, where it has been modified by shearing movements. The country rock has the mineral composition of a mica schist since it consists chiefly of quartz and biotite, but it appears in the field to be as massive as a typical igneous rock. In thin section a partial rude parallelism in the arrangement of the biotite may be observed.

This quartz-biotite rock is cut by veins which strike in general to the northeast, and dip to the southeast. The angle of dip varies from about 30° to 80° or more, and sometimes even passes 90°, so as to dip to the west or northwest. Furthermore, the dip of a relatively steep vein may change abruptly so that the vein is offset, as it were, by a zone of very small dip. These offsetting zones of flat dip (15° to 30°) are usually thicker than the main veins, and in several cases carry higher values. The vein material is chiefly quartz, but one vein is known which contains very little quartz. The gold in the veins is associated not with ordinary iron pyrites, but with arsenopyrite. It is a curious fact that, in spite of the close association in occurrence of the gold and mispickel, one vein, which consists almost exclusively of arsenopyrite, does not carry enough gold to be worked as an ore. This vein of mispickel differs also from the quartz veins in lacking any definite walls. The pure mispickel of the central part of the vein grades through massive hornblendite into ordinary country rock on both sides. Arsenopyrite also occurs disseminated in the massive quartz-biotite rock of the region, with small amounts of chalcopyrite and still less of bornite and pyrite.

[1] U. S. G. S., Livingston Folio, 1894, p. 3.

The mispickel of the country rock and that of the veins seem to have a common origin; there is no evidence to indicate that the latter has been derived from the former. Furthermore, the

FIG. 17. Hand specimen of quartz-biotite country rock of the quartz veins at Jardine, Park Co., Montana. Natural size.

arsenopyrite of the veins was apparently deposited at the same time and by the same solutions that brought in the gold, the

quartz and the tungsten ore, with all of which it is intimately associated.

One of the quartz veins at Jardine presents a remarkable condition. It is about one foot in thickness and dips at about 30°. At the upper end of stopes extending about two hundred feet on the strike and ten to fifty feet on the dip the vein has been subjected to forces—possibly alternate stretching and compression—which have changed a continuous vein into cigar-shaped lenses of quartz. These lenses lie in the plane of the vein, but their axes make angles of 15° to 25° with the line of dip. Around them the massive quartz-biotite rock is converted into a true mica schist, the schistosity wrapping itself completely around each of the lenses. The purely local character of this schistosity appears from the fact that it rarely extends as much as two feet from a quartz lens; usually it disappears in a few inches. The lenses are usually elliptical in section, the long axis of the ellipse (in sections through the thickest part of the lenses) being ten to fifteen inches in length, and about 25 per cent. longer than the short axis. The long axes of the elliptical sections of all the lenses are approximately parallel and stand at an angle of about 20° with the plane of the veins. These lenses vary in length from about six feet to ten feet or more.

The quartz of the veins is often very smoky in appearance. This color in quartz has been attributed[1] to "some organic carbon-nitrogen compound." But it does not seem probable that vein quartz contains any organic compounds. A thin section shows that this quartz contains a multitude of liquid and gaseous inclusions to which the smoky color is probably to be attributed. The liquid globules frequently do not fill the cavities in which they occur. It seems likely that these are globules of carbon dioxide. Associated with the globules cubes sometimes occur, which are isotropic, and of low refringence. They are probably sodium chloride or halite.

The tungsten ore of the Jardine veins is scheelite. It occurs

[1] E. S. Dana, "System of Mineralogy," 1892, p. 187. Dana attributes this idea to Forster.

in irregular bunches in the quartz veins. The chief gangue material is of course the quartz, but mispickel is persistently associated with the scheelite, and small amounts of chalcopyrite and pyrite also occur. Alteration of the ore commonly begins with the iron sulphides; the scheelite is much more stable. Alteration produces about arsenopyrite a granular golden yellow non-pleochroic mineral which is isotropic and of high refractive

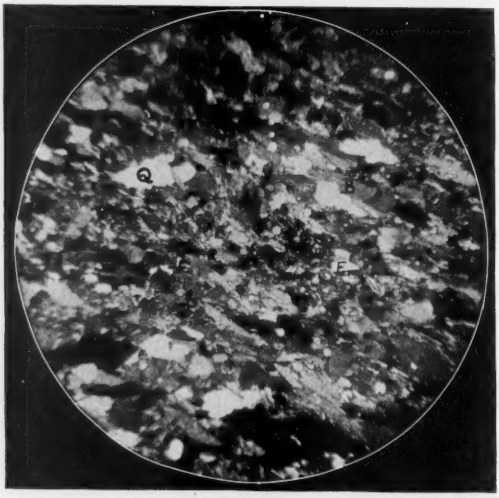

FIG. 18. Quartz biotite rock, country rock of quartz veins carrying gold and tungsten ores at Jardine, Park Co., Montana. *Q*, quartz; *B*, biotite; *F*, plagioclase; *M*, magnetite. Magnified 45 diameters.

index. It is probably the basic hydrous iron arsenate known as pharmacosiderite. Alteration of the scheelite produces a yellow mineral of moderate birefringence and low relief. It is fibrous or micaceous and weakly or non-pleochroic. It is probably the hydrated[1] oxide of tungsten, called tungstite.

The scheelite may be detected in the ore by its high specific

[1] T. L. Walker, *Am. Jour. Sci.*, XXV., 1908, p. 305.

gravity (G. = 6), its yellow to light brown color, and its subresinous luster. It resembles light-colored sphalerite, but the cleavage is not so good and the specific gravity is greater. In weathered portions of the ore the scheelite seems to be nearly as stable as the quartz. In thin section scheelite is distinguished by its very high relief and moderate birefringence. It is uniaxial and positive. The extinction is always parallel with the best cleavage, which is parallel to the base. The mineral has been subjected to strains since its formation, as evidenced by the undulatory extinction. The associated quartz exhibits the same evidence, as well as some granulation. Scheelite in thin section is nearly colorless or grayish like augite. The mineral is coarsely granular to subhedral. Basal sections show traces of pyramidal cleavages.

In Butte, hübnerite has long been known as a minor constituent of the ores, both in the copper veins and also in the gold-silver veins. It is only in the gold-silver veins that it has been found in sufficient abundance to constitute an ore of tungsten in a few places. In the copper veins the mineral occurs in slender prisms which are lenticular in cross section through the development of numerous prismatic faces so narrow that the section is apparently bounded by doubly convex curves of rather large radius. These crystals are dark red to black, and translucent only on the thin edges, where they are dark brownish to blood red. The luster is submetallic, resinous, and often brilliant. The mineral is hard and brittle with a high specific gravity. The crystals developed in vughs sometimes show terminal faces, especially the macrodome; more commonly they have rounded terminations without distinct faces. Most of the crystals, when free, are broken, and show no terminal faces.

The chief production of tungsten ore has come from the Birdie and Scottish Chief mines, east of the great copper mines. The ore here occurs in gold-silver veins in quartz monzonite country rock. The chief gangue material is quartz; other associated minerals include pyrite, marcasite, and smaller amounts of galena, sphalerite, and silver and copper minerals. The hübnerite

is usually in large thin-bladed crystals often arranged in divergent groups. Locally it has been incorrectly called reinite. In the gold-silver veins it is usually dark grayish to black; the blood red color is rare and seems to be due to alteration. The luster varies from brilliant submetallic to shining resinous, resembling sphalerite. Prism faces have numerous vertical striations. In thin section this hübnerite is greenish yellow to brown in color, with variations in tint even in a single crystal. The relief is very high, at least equal to that of zircon, while the birefringence may be

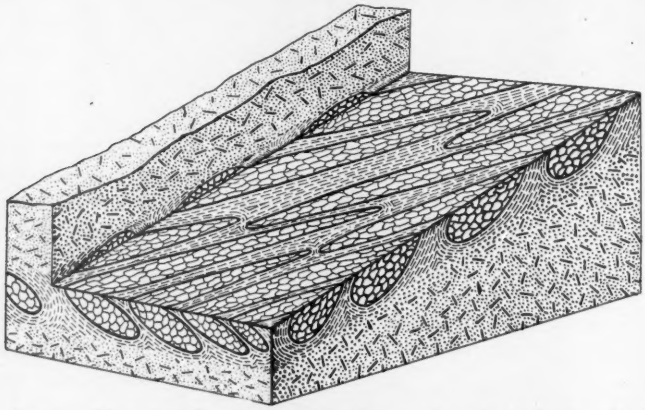

FIG. 19. Diagrammatic representation of a quartz vein at Jardine, Park Co., Montana, which has been converted locally into cigar-shaped lenses, about which the massive quartz-biotite country rock has been converted into a mica schist.

compared with that of the same mineral, since it produces interference colors at least as high as the fourth order in sections of normal thickness. The absorption is very weak, though perceptible, with maximum absorption nearly parallel to the elongation, and minimum absorption along the axis b; that is, $Z > Y > X$, since X is parallel to b, while Z makes an angle of 19° with c. Though the absorption is perceptible, pleochroism is absent or extremely weak. The optic sign is positive, like the

sign of elongation. The bladed divergent crystals are elongated parallel with the prism. Extinction in the vertical zone varies from 0° to 19°. The alteration of hübnerite in these ores seems to be essentially a process of oxidation, since all gradations of change from a yellowish green mineral to a deep blood red condition can be found in going from the central unaltered portions to the outer parts, especially in samples from the oxidized zone. Further oxidation seems to lead to the formation of black oxide of manganese, or pyrolusite. Thin-bladed crystals parallel to 100, and about 0.1 mm. in thickness show the changes very clearly, and also show pleochroism which is distinct, as follows:

Z, grass green, grading into dark brown and blood red.

Y, slightly paler green, grading into brown.

X, yellowish green, grading into yellowish brown and blood red.

The characters both of scheelite and of hübnerite are so distinctive in hand samples as well as in thin section that they will be readily recognized by those who are familiar with their properties.

THE ERZGEBIRGE TIN DEPOSITS.

PART I.

JOSEPH T. SINGEWALD, JR.

Tin mining began in the Erzgebirge about the close of the twelfth century, and for a long time was quite an important industry. At present, the output of this region is an insignificant portion of the world's production. These deposits, though no longer of great economic importance on account of richer and larger deposits in other parts of the world, are, nevertheless, extremely interesting from the scientific point of view, as they show very clearly the genesis of such ores.

The following account is a summary of the literature on these deposits, together with observations made by the author on a recent trip to the points where mining is still being carried on.

GENERAL TOPOGRAPHIC AND GEOLOGICAL FEATURES.

The Erzgebirge extends in a northeast-southwest direction along the boundary between Saxony and Bohemia. The summit of the mountain forms approximately the dividing line between the two lands. The northwestern side has a gentle slope, consisting of relatively broad undulating divides cut by deep valleys. The southeastern slope, on the contrary, is extremely steep, due to a great fault extending along the foot of the mountains, known as the Bohemian thismal fissure, along which a throw of more than 1,500 feet has taken place.

The principal rocks of the mountains are gneisses, schists and phyllites of pre-Cambrian age. Younger formations also occupy limited areas. The mountain building began toward the close of the Paleozoic era, when the area was uplifted as a result of folding. Erosion continued until the Cretaceous period, when the region was again almost completely submerged, and the Cretaceous and following them the Tertiary sediments laid down.

Another period of erosion then set in, which has continued to the present time and has almost completely removed the Cretaceous and Tertiary strata.

Igneous activity manifested itself during two periods—at the close of the Paleozoic era and during the Tertiary. The Tertiary igneous rocks are chiefly basaltic flows and have no connection with the ore deposits. The older igneous rocks are of more acidic types and embrace chiefly members of the granitic family. The granites themselves have modified the adjacent rocks by contact metamorphism and are hence surrounded by zones of such altered rock.

LOCATION OF THE TIN DEPOSITS.

The tin deposits are always closely associated with a granite stock and are hence limited in their occurrence to the regions in which the granites occur. Two belts of granite cut across the Erzgebirge in a northwest-southeast direction, at right angles to the trend of the mountains. One of these belts occurs in the eastern part of the mountains and gives rise to what is generally known as the Altenberg-Zinnwald district, and the other in the western part in the neighborhood of the well known mining towns of Schneeberg, Annaberg, Joachimsthal, etc. While the area of the granite outcrops is much smaller in the first mentioned district than in the latter, the former district is at present of more economic importance.

I. ALTENBERG-ZINNWALD DISTRICT.

A geological sketch map of this district is given in Fig. 1. The gneisses and phyllites are cut by a great fissure along which quartz porphyry, granite porphyry, and granite have been intruded. Along this fissure there has been an extensive sinking of the western side with respect to the eastern, so that on the east only the coarse-grained phase, or lower stage, of the gneiss formation is represented; whereas, on the west only the fine-grained phase, or upper stage of the gneiss formation with the overlying phyllite formation, is found.

The oldest of the eruptive rocks is the Teplitz quartz porphyry. In its typical development it consists of a reddish brown to flesh-colored compact ground mass with phenocrysts of quartz, feldspar and mica. Though essentially a fissure filling, it has on its west side overflowed the fissure and covered the adjacent rocks. Since it has in places flowed over rocks of Upper Carboniferous age, its age is fixed as younger than Carboniferous. East of the Teplitz quartz porphyry is a massive dike of granite porphyry. In general, this has been intruded along the contact of the Teplitz quartz porphyry and the gneiss; but northeast of Zinnwald, for a distance of over a mile, the main dike lies wholly within the gneiss, but has at the same time sent a smaller branch through the Teplitz porphyry. This rock consists of a fine-grained ground mass of quartz and feldspar with tufts of chlorite, and large phenocrysts of the same minerals. The striking feature of the rock is the unusually large phenocrysts of a reddish orthoclase, which may attain a length of over one inch.

Cutting both of the above described porphyritic rocks is a series of granite stocks. Northeast of this series of outcrops at Barenstein, is a small outlier which, judging from the prolongation of the zwitter area, probably continues for some distance to the southeast close to the surface. The granite of all of these outcrops has the same mineralogical composition, namely, quartz and orthoclase, together with a plagioclase low in calcium, and a dark colored lithia mica poor in magnesia. All are accompanied by tin deposits, and their outcrops, as well as the surrounding impregnated zones, are marked by hundreds of old dumps and a number of "pinges," as the basins resulting from the caving in of old workings are called (see Fig. 3).

At present ore is being mined at four points in this area—near Sadisdorf, at Altenberg, Zinnwald and Graupen. Since the ore occurrence, as well as the ores themselves, is somewhat different in every one of these places, they will be taken up separately for detailed description.

1. *Sadisdorf.*

One mile southeast of Sadisdorf is an impregnated zone in the gneiss at the Teplitz quartz porphyry contact. Tin-copper veins were formerly extensively worked here, and the caving in of the workings has caused the formation of a "pinge." On account of its former copper output, the mine has received the name "Sadisdorf Copper Mine." In the "pinge," close to the porphyry contact, a small granite stock is exposed, surrounded on all sides by the gneiss. As accessory constituents, even in the freshest specimens, are light yellow irregular grains of topaz, fluorspar and cassiterite.

The granite is everywhere traversed by innumerable small tin-bearing quartz stringers, on both sides of which for a short distance, usually only an inch or two, the rock is dark colored. This dark colored rock, which the Erzgebirge tin miners call "zwitter," is altered granite, in which the feldspar has been replaced by topaz and quartz, usually with the preservation of the outline of the replaced feldspars. In addition to these minerals, small cassiterite and fluorspar grains have also been deposited, and, locally, pyrite, arsenopyrite and chalcopyrite. More rarely, chalcocite and cuprite occur. These countless quartz stringers, with the adjacent impregnated rock, were the object of the former mining operations. At the present time the deposit is again being worked on a small scale, but now solely for wolframite and molybdenite. A mill has just been erected a short distance below the mine for the handling of this ore, and the output will be increased.

The ore occurs in an eighteen-foot vein, which cuts through the granite with a dip of about 45° to the south. It is a complex vein with very irregular boundaries. The chief filling is a light grey quartz with locally considerable fluorspar. Near the footwall occur large nests of pure wolframite, which together with the enclosing quartz are cut by secondary horizontal stringers of quartz carrying cassiterite and gilberite. These stringers are again cut by still younger vertical fluorspar stringers. Toward

the hanging-wall a great deal of molybdenite and also a little zinnwaldite are encountered. Along both the foot and hanging-wall, the vein filling contains fragments of a friction breccia similar to the filling itself, but characterized by the presence of bismuth and bismuthinite. The hanging-wall country rock is a very much decomposed granite, which carries, besides considerable chlorite, cassiterite and copper minerals, and is also impregnated with the gangue minerals. Through this decomposed and impregnated rock cuts a parallel vein, also rich in molybdenite and wolframite.

The output of this mine in 1907 was nearly 3.4 t. wolframite and 1.3 t. molybdenite.

2. *Altenberg.*

Of far more importance and interest is the deposit at Altenberg, where a bismuth-bearing tin ore is being mined. The output in 1907 was 46.8 t. cassiterite and about .62 ton of bismuth chloride. Mining began here in the middle of the fifteenth century, and the present Zwitterstock Company dates back to 1546. As a result of the caving in of the early workings an enormous "pinge" has formed, which now has a length of over 1,000 feet, a maximum width of 600 feet, and a depth of over 150 feet. After a number of smaller preliminary breaks, the main cave-in occurred in 1620. Further cave-ins, as a result of subsequent mining operations, have brought the size of the "pinge" up to its present large dimensions.

The workings at present are confined to the small granite stock, which has intruded the granite porphyry. This stock is traversed by countless minute stringers of tin ore, which cut through the granite in all directions. These stringers, which are usually so narrow as to be scarcely perceptible, are accompanied by adjoining zones of ore-bearing rock or zwitter, and they are so closely crowded that almost the entire granite mass has been converted into such zwitter. This has given rise to the name "Altenberg Zwitterstock." The mine exposures show that this impregnation has been confined to the upper portion of the granite, and

already at a depth of 700 feet normal granite is encountered, in which zwitter bands are completely lacking or only sparingly present. Veins of appreciable width are extremely subordinate, and the chief object of mining has been the "Zwitterstock."

The cassiterite occurs in the zwitter as fine grains which are usually so small as to be invisible to the naked eye. The percentage of tin is extremely low, varying from .1 to .9 per cent. with an average of about .3 per cent. The bismuth content is about .002 per cent. It is only as a result of the peculiarly favorable conditions existing here that it is possible to still work such a low grade ore.

In the first place, as a result of the complete impregnation of the granite, practically all the material handled is ore, and hence there is no loss through the handling of waste.

A second and more important factor, however, is the method of mining that can be employed here. Even the early mining operations had extended down to the unimpregnated granite. The method of mining then employed was that of "fire setting"; that is, fires were built in the openings, and as a result of the heating of the rock, concentric shells would break away. In this way enormous dome-shaped chambers were formed, and one of the interesting sights in the mine to-day are several of these old domes which are still standing. These domes stood one over another, and as they became larger and larger could not longer support their weight, and finally collapsed, forming the "pinge." This resulted in a complete shattering of the "Zwitterstock," so that it now exists as a mass of broken rock, filling a basin formed by the surrounding solid rock. The removal of this shattered rock is much easier and cheaper than the removal of solid rock, as very little blasting and drilling is necessary. A shaft has been sunk in the adjacent solid rock to a depth of about 700 feet, that is, to the bottom of the débris. From the shaft a level with a number of side drifts is driven out under the "pinge," and the shattered material removed while the overlying rock is held up by timbering. When the far side of the "pinge" is reached, the timbers are removed as far as possible, and the whole allowed to

cave in. This results in a still further enlargement of the "pinge" at the surface. The same operation is then repeated.

The machinery is also very simple and inexpensive, as both cage and pump are operated by water power. At the 400-foot level is a drainage tunnel which carries off all the water. The water from the lower levels is pumped up to the level by means of a water power pump, which operates under a pressure of thirteen atmospheres.

The mill machinery is also run by water power. As the ore comes from the mine, it is crushed into smaller lumps, and these fed to the stamps. The stamps are wooden beams provided with an iron base. The material coming from the stamps is passed through two troughs, in which the coarser and finer heavy materials are caught. These are then further concentrated by repeated washing on percussion tables. When sufficiently concentrated, which is determined by the color of the concentrates, they are dried in ovens, and then placed in troughs and covered with hydrochloric acid in order to bring the bismuth into solution. When this leaching, which is continued for a week or more, is completed, the bismuth chloride is drawn off and poured into vats full of water in order to precipitate the bismuth. The insoluble residue remaining in the acid troughs contains the cassiterite, and this is again washed on percussion tables until the color shows that it is sufficiently concentrated, when it is ready for the smelter.

3. *Zinnwald.*

At Zinnwald the ores are again of a different character, and the principal output is wolframite, while tin is subordinate in amount. Instead of a zwitterstock, true veins occur. A long narrow granite stock has been intruded into the Teplitz quartz porphyry, and the veins occur in it and also extend out into the surrounding porphyry. These veins have been cited as a typical example of ento-kinetic fissure resulting from the contraction of a cooling rock mass.

There are two systems of ore-bearing fissures—a system of

extremely flat dipping, and a system of vertical fissures. The flat dipping veins, or "Flötze" as they are called by the miners on account of their flat dip, are approximately parallel to the boundary of the granite. They were formerly thought to be actually parallel to the boundary, but they dip somewhat more gently than the boundary and hence pass over into the Teplitz quartz porphyry, in which one has been worked in the Gnade Gottes mine for a distance of 600 feet from the contact and still shows itself workable. In most cases, however, they become poorer and pinch out rapidly as soon as they cross the boundary. The dip of these veins varies from 15° to 30°, and, while their width may attain as much as five or six feet, it usually ranges between one half and two feet. The distance between the veins is also extremely variable, ranging from three to one hundred and twenty feet or more. About twelve of the veins have proved themselves workable. The steep dipping veins have a general northeasterly strike, and their width is usually not great, seldom exceeding eight inches.

The filling in both systems of veins is the same. The chief gangue minerals are quartz and zinnwaldite, as the lithia fluorine bearing mica is called. This mica carries 3.36 per cent. lithium, and was formerly worked for its lithium content. These two minerals usually do not occur irregularly intermingled, but seem to have been deposited in layers in such a way that the individual layers are parallel to the walls. Then again, one of the two minerals may occur to the almost complete exclusion of the other. Occasionally feldspar occurs in place of the quartz. The ore minerals, which are principally cassiterite and wolframite, vary greatly in amount within short distances, and occur irregularly distributed through the quartz and mica, and also crystallized in the middle of the veins. In rare instances almost the entire vein has been filled with pure cassiterite; in general, however, the cassiterite does not occur in large masses, but in small grains sprinkled through the quartz and mica. The wolframite, on the other hand, occurs in coarser grains and crystals, and occasionally, especially along the walls, in compact masses weighing over a

hundred pounds. It seems that the wolframite inclines to occur in greater abundance where the sulphides are present. This mineral, which was formerly regarded as worthless, was thrown out on the dumps, and within recent years all of the old dumps have been re-worked several times, every time more thoroughly as the increasing value of the mineral made it profitable. Sulphides are present in small amounts only, and occur solely in druses along the middle of the veins.

These two systems of veins do not cut each other, but the filling of one passes over into the other at the vein crossings, showing that the veins are all of the same age. They are, however, cut by a later system of fissures which has faulted them. In general, the throw scarcely amounts to as much as the width of the faulted vein, but may be as great as thirty feet or more. These faults are frequently filled with a friction breccia.

In addition to the tin-bearing veins, greisen has also been mined here. This occurs along the veins on both walls, and also in large masses apparently not connected with veins of appreciable width. All stages of transformation from granite to greisen are encountered and frequently the greisen areas include unaltered masses of granite. The greisen is a medium to coarse grained rock, though at times inclining to fine grained, the essential constituents of which are a light grey quartz and a greenish or brownish green mica. Topaz, which formed such a prominent constituent in the Altenberg zwitter, is here subordinate in amount. A dark violet fluorspar and finely disseminated cassiterite also occur. The average amount of cassiterite in the greisen is perhaps scarcely .2 per cent., but in places it has been mined with as much as .4 to .5 per cent.

Most interesting and genetically important is an exposure described by R. Beck in the Gnade Gottes mine. This mine is on the east border of the granite outcrop, just north of the Saxon-Bohemian boundary, and is working chiefly in the Teplitz quartz porphyry. This rock, which is penetrated by countless narrow bands of zwitter, is cut by small granite dikes, which are apophyses of the main granite mass. As these dikes also cut

the zwitter bands, the period of formation of the tin ores is quite definitely fixed. They were formed after the intrusion of the main mass of the granite, and yet before the complete cessation of eruptive activity, that is, before the complete solidification of the granite massive.

The same limitation of the ore to the upper portion of the granite which is found at Altenberg is also encountered here. The Hilfe Gottes adit, which extends from the north as far south as the Bohemian border, where it is about three hundred feet under the surface, exposed only small poor veins at the granite-porphyry contact, and further in the granite the veins were practically without ore.

In 1907, the output of the Saxon portion of the district was 65 t. of wolframite and 1.3 t. of tin ore. During the year previous the Bohemian portion produced 55 t. of wolframite.

4. *Graupen.*

Tin placer mining began at the close of the twelfth century in the Graupen region. This was later followed by extensive working of the primary deposits. These consisted in part of "zwitterstock" masses where the entire rock was mined, the locations of which are marked by a number of old "pinges"; and in part of true veins, in the neighborhood of which numbers of old dumps give evidence of the former activity. At present mining is restricted to one vein near Ober Graupen, the Luxer vein, and this is being conducted on a very small scale. These deposits all occur in close connection with the granite stock of this region, and granite dikes which cut the surrounding gneisses and porphyries. The veins are characterized by the permanence of perthite and fluorspar in the gangue.

The Luxer vein is being worked through the new Martini adit, which extends through the barren country rock for a distance of 800 feet in a north-northeasterly direction to the vein, and then north along the vein. In its northerly strike, this vein departs from the usual east to northeast strike of the veins of this region. The dip is about 35° to the west, and the width

from 8 to 12 inches. Occasionally it splits into several approximately parallel stringers, which may again unite or gradually die

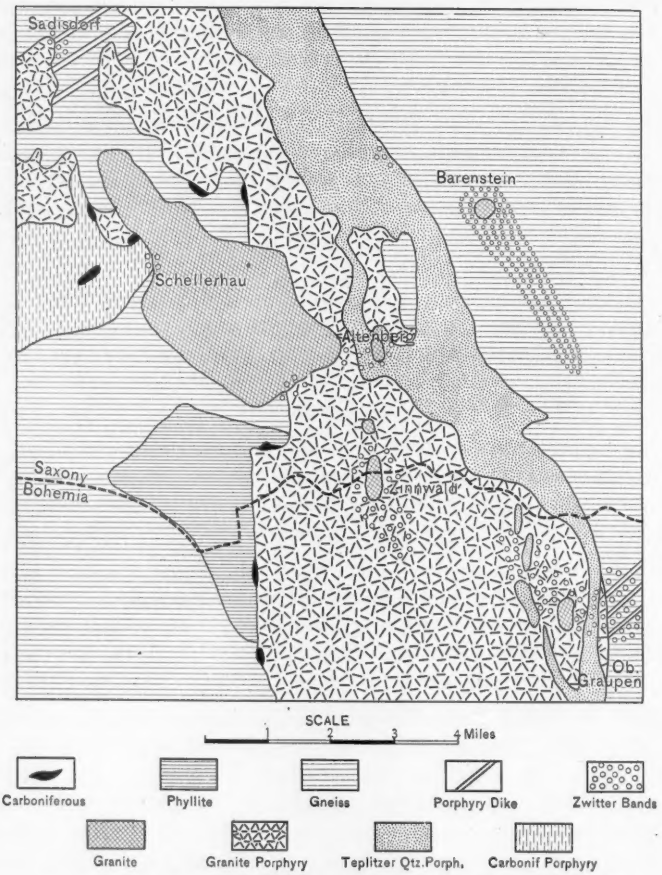

FIG. 20. Geological Sketch Map of the Altenberg-Zinnwald Region (K. Dalmer).

out. Within the vein are frequently blocks of very much decomposed gneiss. The vein filling is extremely variable. The pre-

vailing gangue is a milk white quartz. Locally, however, this gives place to coarsely crystallized orthoclase intergrown with albite and to violet blue fluorspar. Dark green lithia mica and whitish steinmark, a compact variety of kaolinite, are subordinate gangue minerals.

The brown or yellow cassiterite, where it occurs in considerable amount, is usually relatively evenly distributed, and in fairly large short prismatic crystals known as the Graupen form. Wolframite also occurs, and where the fluorspar is present, small amounts of chalcopyrite and galena.

The structure of the vein is a medium coarse grained, with occasionally an arrangement of the quartz, when it predominates, at right angles to the walls. The perthite and fluorite often show a brecciated structure as a result of subsequent crushing.

Where the veins are rich in quartz, the country rock has its feldspar replaced by quartz and a light to green colored lithia mica, and is impregnated with fluorite and cassiterite. On the other hand, when the perthite and fluorspar are more prominent, the original feldspar of the gneiss has been added to by the formation of perthitic orthoclase, and an impregnation with mica, fluorspar and cassiterite has also taken place. A transformation of the country rock into "zwitter" or greisen has not been observed. R. Beck considers this vein as forming a transition to true pegmatite dikes and closely related to the tin-bearing pegmatites of the Carolinas.

(To be continued.)

CLAY SEAMS OR SO-CALLED HORSEBACKS NEAR SPRINGFIELD, ILLINOIS.

T. E. SAVAGE.[1]

Clay filled fissures in the form of clay seams are not uncommon in the Upper Carboniferous coal beds of the United States. They have been described from Pennsylvania, West Virginia, Ohio, Indiana, Illinois, Iowa, Missouri and Kansas. In some cases the clay appears to have been derived from the fire clay below the coal, and in others its source seems to have been some horizon above the coal.

Describing clay seams in the Kansas coal beds, Crane[2] says:

"There is always an upward displacement of shale at the upper extremities of the clay veins . . . in all cases the clay in the clay veins is similar to that underlying the coal; and . . . the horizontal position of the coal or shale strata has not usually been disturbed."

Concerning their probable origin he states:

"Long after the coal was formed and consolidated almost to its present condition, vibratory movements of some kind fissured the strata including the coal beds. After the fissures were formed the fire clay below the coal was squeezed upward, filling the fissure by the process of ordinary creeping. The upturning of the shale laminæ near the upper part of the fissure would be readily produced by the upward movement of the clay under the power which forced it along."

His Fig. 23 on page 203 shows a clay seam in which the down bending of the edges of shale and coal indicate that the movement of the clay was downward in the fissure, while Fig. 29 on page 209 represents a clay seam in which the clay appears to have moved up from below the coal.

The coal field about Wier City is mentioned as showing very numerous clay seams. On page 164 is described coal on the Kepple farm in that vicinity, four feet thick, with a floor of good fire clay, having a roof composed of six feet of sandy shale above

[1] Illinois Geological Survey.

[2] Crane, Univ. Geol. Surv. Kan., Vol. III., pp. 211 and 212.

which occurs two feet of fire clay, which is succeeded by more sand and shale. The above conditions of roof and floor would seem to be favorable for the development of clay seams on the same principle as those occurring in the Springfield area.

Keyes[1] states that:

"Ruptures, or more or less vertical, simple fissures, which are merely a separation of different parts of the coal seams without displacement, are not uncommon in Iowa. Clay usually fills the fissure which may be from an inch to a foot or more in width."

From the figures which he gives of these clay seams, the direction of movement of the clay in the fissures cannot be determined.

Bain[2] has figured a clay seam in which the down bending of the edges of coal and roof slate at the top of the coal seam indicate the downward movement of the clay in the fissure, similar to those in the Springfield area where the fissure passes nearly vertically into the coal. The roof of the coal in this region consisted of one and one third feet of black, fissile shale, succeeded by about four feet of limestone above which were seven feet of pyritic shale.

Discussing clay veins in the Indiana coal seams Ashley[3] says:

"They are usually associated with faults and are probably due to the action of the same forces. . . . In a few places the clay appears simply to fill the space made by the separation of the rocks on either side of the line of faulting. In most cases the coal and the rock on either side seem to have been broken up . . . and when the clay was forced up through this mass, it extended out into it, following lines of least resistance, and catching up masses of it in the main clay body."

In his sketches of clay seams, Figs. 3 and 4 on page 58 of this report, there seems to be indicated a down bending of the upper edge of the coal on the overhanging side of the fissure without any real faulting of the bed. On page 468 he describes a coal seam on the Conce land, four and one half feet thick, which is overlain by twenty-two inches of black shale, above which are three feet of clay shale. Of another mine, nearby, the fire clay

[1] Keyes, Iowa Geol. Surv., Vol. II., p. 189.
[2] Bain, Iowa Geol. Surv., Vol. V., p. 399.
[3] Ashley, 23d Ann. Rept. Dept. Geol. and Nat. Res. of Indiana, p. 59.

is said to give no trouble creeping, possibly because too dry. Clay seams are said to be common in the coal in this vicinity.

The conditions here of a dry fire clay floor; a hard, black shale roof, followed by a three-foot bed of clay shale are consistent with the state of things in the No. 5 seam of the Springfield area.

Concerning the clay seams in Ohio coal beds, Orton[1] states that:

"Clay veins, one of the most serious drawbacks to mining in many fields, are connected with and proceed from the fire clay floor. They seem to have been formed in the earlier stages of the history of the coal seam by some inequality of pressure or resistance whereby the bottom clay was forced in thin sheets through the hardening coal."

In his report on the coals of Michigan Lane[2] says that clay-filled veins, or clay seams, are but little known in Michigan. An inspection of the various shaft sections given in this report shows a remarkably small amount of fire clay or soft shales associated with the coal seams, and a great predominance of sandstone and hard shale. Such strata associated with the coal beds would not be favorable for the development of clay seams.

In discussing clay veins, more especially those of the Pennsylvania coal field, Gresley[3] thinks that the clay vein fissures may be placed in the category of earthquake phenomena. He says:

"The fissures remained open long enough to allow weathering and the gradual disintegration of their ragged sides. The character and aspect of the finer clay and the more fragmentary ingredients of the clay veins are such as to indicate that they were principally derived from the walls of the veins. In most cases the vein stuff comes by descent from the walls, in other cases they are intrusively filled by the underclays which have been squeezed up into the open cracks in the overlying coal."

It seems probable that clay seams have been formed in different ways under differing conditions of roof and floor, and varying degrees and kinds of strains to which the strata were subjected. It is not possible that earthquake phenomena or general crustal strains, such as produce widespread faulting, could be concerned

[1] Orton, Geol. Surv. of Ohio, Vol. V., p. 143.
[2] Lane, Geol. Surv. of Mich., Vol. VIII., p. 126.
[3] Gresley, Bull. Geol. Soc. of Amer., Vol. IX., p. 35, *et seq.*

in the formation of the fissures of the clay seams in the Springfield region. Fractures from the above mentioned causes would not be limited to a few feet in vertical height, or to one particular coal seam, as in area under discussion.

Clay Seams Near Springfield.—The principal coal seam exploited in western Illinois, over the area between Springfield and Peoria, was designated in the Worthen reports as No. 5. The following section shows the character of the strata associated with the No. 5 coal in the region about Springfield.

	Feet.
Sandstone or shale	10 to 30
Light gray shale or soapstone	1½ to 4
Limestone cap rock	½ to 1⅔
Black, fissile shale	2½ to 4½
Coal (No. 5)	5 to 6½
Fire Clay	1½ to 5

One of the conspicuous features of the No. 5 coal seam is the presence of numerous clay-filled fissures that extend down into, or through, the coal seam from the overlying beds. The fissures are generally from two or three to sixteen inches in width, although the larger ones attain a width of three or four feet. Their walls are slickensided, but do not show any traces of weathering. The spaces between the walls are filled with a light gray shale or soapstone.

These fissures, with their fillings, are known to the miners as horsebacks. There is no regularity in the distance between these horsebacks, or clay seams, or in the direction in which they extend. In some mines they are encountered about forty to sixty feet apart, while in others they are separated by a distance of two hundred to four hundred feet, or more. They traverse the coal seam in various directions, no single direction greatly predominating even in the same mine.

The shale filling the fissures is light gray in color and is generally rather soft. In rare cases it is so hard that it emits sparks when struck with a hammer, but usually it soon slakes down into an incoherent mass upon exposure to the air. Where the horseback enters the top of the coal seam the fissure at once becomes

wider. The upper laminæ of the coal, immediately adjacent to the fissure on the overhanging side, are more or less steeply bent downward; the bending or buckling of the layers fading out laterally within a few feet from the fissures. Fragments of the black shale, from the roof of the coal, were seen at many points in the clay filling of the horsebacks from five to twenty-nine inches below the top of the coal. In mine No. 5 of the Springfield Coal Mining Company, a fragment of coal, six inches long and three fourths of an inch in thickness was found in the clay of a horseback nine inches below the bottom of the coal seam.

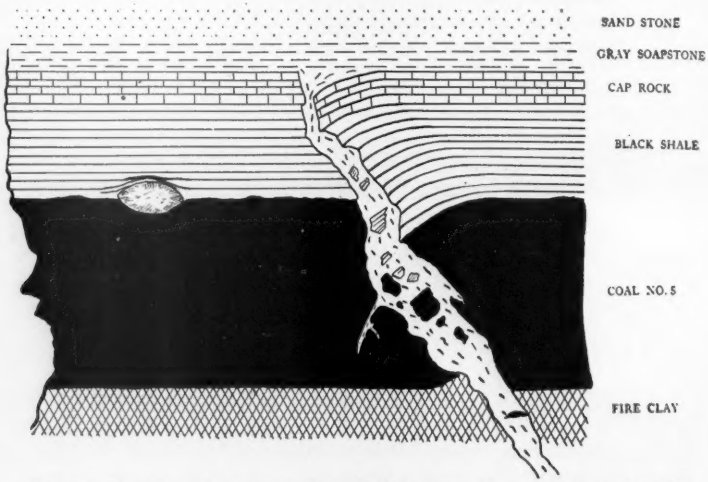

FIG. 21. Typical Clay seam or horseback in Mine No. 5 of the Springfield Coal Mining Co.

In the mine last mentioned there were seen in three of the horsebacks a slight upward bending of the lower edge of the coal on the side of the fissure opposite to that in which the down bending at the top occurred. This upward bending at the bottom, however, is only one third to one half as great as the down bending of the coal at the top of the seam in the same horseback. When the clay seam passes into the coal bed in a nearly vertical

direction there is a down bending of the coal at the top of the seam on each side of the fissure. However, the more nearly vertical the direction in which the horseback cuts through the coal, the less is the distance through which the edges at the top and bottom of the seam are bent.

In no instance was there seen a true faulting of the beds. I wish to emphasize the fact that in no case was there a slipping of the middle part of the coal seam on one side of the fissure above the level of the corresponding part of the seam on the opposite side. The only vertical displacement is a downward pushing of the cap rock and roof shale, and a down bending of the upper laminæ of the coal on the overhanging side of the fissure, through a vertical distance of from two to twenty inches; and, less frequently, a much smaller upward bending of the lower edge of the coal seam on the opposite side of the fissure, as shown in Fig. 21.

In this area the fissures have a very limited vertical extent. In the Mechanicsburg mine a coal seam was formerly worked about thirty-five feet above the No. 5 bed which is at present being mined. Although these two coal seams are separated by an interval of less than forty feet, the No. 5 coal is traversed by numerous clay seams, while none were encountered in the upper bed.

It seems certain that there was a somewhat ready yielding of the coal mass in a lateral direction when the fissures were formed. This is shown in the fact that the walls of the fissures are wider apart in the coal bed than in the overlying roof shale and cap rock. The clay seams always cut the bed in an oblique or a vertical direction, never following partings or stratification planes of the coal seam, even where these are well marked. The amount of downward slipping of the cap rock is always less than the extent to which the upper edge of the coal seam overhanging the fissure is bent downward. All of the movement, both horizontal and vertical, that has taken place in connection with the clay-filled fissures, seems to have been made possible by the yielding of the materials within the coal seam itself.

That the coal offered accommodation to the strains that caused

the formation of the fissures is shown by the fact that within the coal seam the smaller fissures often divide into a number of branches which eventually die out without passing entirely through the bed.

The clay filling the fissures is thought to have been pressed downward through the break in the cap rock and roof shale, into the coal, from the bed of gray shale or soapstone overlying the cap rock. As this clay was forced downward into the fissures it caught the overhanging and unsupported edges of the cap rock, roof shale and coal, bending those edges downward on the overhanging side of the fissure.

That this clay was, for the most part, squeezed downward from above the coal horizon is indicated by the manner in which the upper edge of the coal overhanging the fissure has been bent downward to a much greater extent than the lower edge of the coal on the foot-wall side has been forced upward. It is shown in the fact that fragments of black shale from the roof of the coal are common in the clay filling of the horseback several inches below the top of the coal seam; the fragments of coal also occur in the clay some inches below the bottom of the seam. In no case were coal fragments found in the clay filling at a level higher than the top of the coal.

Suggested Origin of the Local Clay Seams.—It is thought that the formation of the clay-filled fissures was intimately related to the character of the beds above the No. 5 coal. It is probable that the character of the underlying fire clay, which here is dry and does not creep readily, is also a conditioning factor. The fissures were not formed, as at present, until after the vegetal mass composing the coal seam had been compressed to near its present volume. This is shown in the fact that the clay seams show no bending or buckling, such as would result if much compression of the coal had occurred after the horsebacks were completely formed. Where the lower edge of the coal rests upon the clay filling the horseback, the laminæ are not curved upward adjacent to the fissure as they would be if the coal at a distance from the fissure had been compressed or set-

tled downward since the horseback was formed. That a degree of consolidation of the coal sufficient to permit of jointing had occurred prior to the formation of the horsebacks is shown by the fact that in some places the clay from the fissures has spread into the joints of the coal adjacent to the horseback.

Campbell[1] suggests that joints are developed early in the process of coal formation, and that the carbonization of the coal beyond the lignite condition, depends upon the presence of joints and cleavage planes along which the gases could find a way of escape. If this is the case, there would be a considerable amount of compression and contraction of the coal seam after the joints were formed, before the vegetal mass reached the condition of bituminous coal.

It is assumed that as the mass of vegetal material, under the weight of overlying sediments, was slowly transformed into coal, there would be somewhat unequal contraction in different parts of the seam, owing to the lack of homogeneity of the vegetal materials making up the coal beds; and that the contraction of the coal materials continued long after a high degree of consolidation of the coal had taken place. So long as the materials possessed some degree of mobility the unequal shrinking in the different parts of the coal seam would be equalized by the movement of some of the mass towards the points of least pressure. When the consolidation reached a certain point such adjustment would be no longer possible. After this, the continued unequal shrinking of the vegetal mass would cause unequal strains in the roof of the coal under its load of superposed sediments.

If the roof of the coal seam was a soapstone, or somewhat plastic shale, the mobility of the shale particles would permit this zone to adjust the inequalities of strain resulting from the unequal contraction of the coal seam. Such conditions exist in the roof of coal No. 6, in the Carterville-Zeigler district of southern Illinois. Rock rolls or depressions in the top of the coal are here common, but no clay seams penetrate the coal bed. In the vicinity of these rolls the roof shale is cut by slickensided zones

[1] Campbell, Economic Geology, Vol. I., No. 1, p. 30.

for a distance of several feet from the center of the roll, indicating a considerable lateral movement in the shale in accomplishing the adjustment of the strains. However, the roof of coal No. 5 is a hard, brittle shale whose constituent particles do not possess the mobility requisite for such adjustment. If the limestone cap rock was very thick it might be able to withstand, without fracture, the unequal strain due to the unequal contraction in the underlying coal seam. The cap rock of this coal is thin, averaging only twelve to fourteen inches. The combined strength of the roof shale and cap rock was not sufficient to withstand the unequal strain to which they were subjected, and fissuring of the beds resulted.

Immediately above the cap rock of this coal seam is a bed of rather soft, gray shale or soapstone whose particles were sufficiently mobile to bring about adjustment in the unequal strains which, by the fissuring of the roof shale and cap rock, had been transferred to this higher horizon. The materials from this shale horizon were immediately squeezed downward through the fissures as a wedge into the coal seam until the inequality of pressure was adjusted. Under these conditions the place in which adjustment was accomplished was limited to a narrow zone below the point where the fracture was made in the roof shale and cap rock. Hence the effects are confined to a narrow zone horizontally but they became thus strongly marked in a vertical direction.

It is probable that from time to time, as the shrinking in the coal mass continued, more clay was forced downward into the coal seam, fissuring it still deeper and spreading the walls of the fissure constantly wider apart. The abundant evidences that the clay filling the fissures in the Springfield coal seam was pressed down from above the coal have been given on a preceding page. In this manner also the slickensiding was accomplished by the slipping of the clay in the fissure, and not by the movement of the walls of the fissure upon each other.

It is thought that the principle of unequal contraction in the different parts of the coal seam, during the progress of its con-

solidation, applies also in the formation of the more common types of rock rolls in the top of coal seams. The character and sequence of the beds above the coal are considered the chief factors in determining whether rolls or clay seams will be formed in the adjustment of the strains arising from such unequal contraction.

DISCUSSION

This department has been established by the editors in order to afford to those interested in questions relating to economic geology an opportunity for informal discussion. Contributions are cordially invited either in the form of discussion of more formal papers appearing in earlier numbers or bearing upon matters not previously treated. Letters should be directed to the Editor, Sheffield Scientific School of Yale University, New Haven, Conn. The full name of the author should be attached to all communications.

IRON ORES OF IRON SPRINGS, UTAH.

REPLY TO REVIEW BY J. F. KEMP.

Sir: Professor Kemp's review of the report by Mr. Harder and myself on the Iron Ores of the Iron Springs district, southern Utah, contains the following invitation: "The reviewer hopes that the authors of the Bulletin will feel no hesitation in continuing the discussion, even though authors sometimes are reluctant to reply to a review." The invitation is accepted in the spirit in which it is offered.

In many western mining districts detailed study has shown silication of limestones near their contacts with intrusives. A general explanation, including that of Professor Kemp, has been that the silicated phases contain accessions of silicates from the intrusive rocks in such quantity that no considerable volume decrease has resulted from the elimination of the carbonates. But other explanations have been offered. Barrell,[1] in his work on the Marysville district, argued that the accessions of new material from the magmas, especially in an early stage of intrusion, did not prevent a great decrease in volume of the limestone in its contact phase—perhaps as much as 50 per cent.—due prin-

[1] "Geology of the Marysville Mining District, Montana; a Study of Igneous Intrusion and Contact Metamorphism," by Joseph Barrell. Prof. Paper U. S. Geol. Survey, No. 57, 1907, p. 148. See also *Am. Journ. Sci.*, Vol. 13, 1902, p. 285.

cipally to elimination of carbon dioxide, and argued that carbon dioxide was expelled only so far as silica was present to replace it in combination with lime. In the Iron Springs report the hypothesis is favored that the limestone contact phase has suffered an even greater diminution in volume, the substances now present representing a residuum of only 20 per cent. or less of the volume of the original rock. We regard this explanation favorably for these reasons: There is nothing in the density, texture or structure of the contact phase to tell what proportion of the original volume of the limestone it represents, for instance, there is to be found no crumpling of the beds, on which the shortening of the rock mass can be measured, and likewise there is nothing to show that reduction has not taken place. Comparing the fresh limestone and contact phase chemically, it appears that in the fresh and altered limestones the ratios of silica and alumina remain about the same. In the contact phase they are not substantially different from the residual clays found from the weathering of a limestone. If the silicates in the contact phase were introduced from the magma, it seems strange that they should give in the aggregate so nearly the same proportions of silica and alumina as were present in the original limestone. It seems fully as probable that the silica and alumina represent part of a residuum from the limestones from which lime, magnesia and potassium, and carbon dioxide have been partly expelled. Further, if silica and alumina had been introduced with little or no decrease in volume one might expect to find evidences of bedding occasionally in the contact zone.

Professor Kemp calls attention to the fact that the silica and alumina ratios in the intrusive itself are not far different from those in the limestone contact phase, implying that solutions escaping from this rock into the limestone might carry silica and alumina in substantially these proportions. The writer doubts the validity of this argument, in view of the known tendency for solutions escaping from igneous masses to adjacent rocks to have a composition not like that of the average parent magma and usually contrasting widely in proportions and even in substances with the main body of the magma.

Professor Kemp's objection to the hypothesis offered for the Iron Springs contact phases is principally on the score of the great decrease of volume it requires. He makes a number of interesting recastings of our analyses to show the great reduction of volume required. The authors fully realize the magnitude of this reduction, in fact the quantitative comparisons made on the circular diagrams published in our report may be read directly in terms of volume without the calculations of the sort made by Professor Kemp. The densities of the fresh and altered rocks being so nearly equal, the losses in weight read directly from the circular diagrams, assuming constancy of alumina and silica, tell the loss of volume. Thus the loss of weight, read directly from the diagrams, is about 85 per cent. In terms of volume, allowing for known 6 per cent. difference in density, the loss of volume is about that calculated by Professor Kemp, 80 per cent. Assuming this loss to be entirely by linear shortening, the 60-foot contact band is the residuum of a limestone zone originally 300 feet wide, and a little wider if the linear shortening is calculated radially from the igneous rock as a center.

If specific evidence shows the hypothesis of great diminution of volume to be a possible one, shall it be discarded because of general improbability? Improbability depends upon viewpoint. An intrusive rock enters a limestone. It makes way for itself in a manner not yet clearly understood—by overhead stoping, by marginal assimilation, by crowding the adjacent rock aside through folding and faulting, by eliminating easily soluble constituents in the wall rock, or some combination of these processes. The limestone contact phase of the Iron Springs district, in common with that of many other districts, was developed early in the intrusion—clearly prior to the escape of certain ore-bearing and other solutions coming under the general head of igneous after-effects. The contact phase was developed under what seem to have been conditions of great pressure and heat, judging from presence of heavy silicates and glass, though the depth was not great. Such conditions may be supposed to be favorable to the solution of limestone. If pressure accompanies and aids solution, the closing of solution-spaces seems a reasonable con-

sequence. Is it to be expected that the carrying in and precipitation of new materials by solutions should be so delicately balanced with the solution of the limestone that spaces formed by solution should everywhere be exactly filled by the new material when pressure is so ready to close them? The first great compressional movement of intrusion seems to have been followed by a relaxational movement, resulting in the development of fissures and openings through which solutions moved freely. Diminution of volume was no longer required by the pressures. Then came abundant accessions of new materials, including the ores, in solutions probably from the intrusives, filling spaces and thereby tending to increase volume. To us there is nothing improbable in the view that an intruding magma in an easily soluble substance like a limestone may at the start make room for itself rapidly by solution of adjacent limestone through the aid of hot gases and waters accompanying the intrusion and with the aid of ever-present pressure, and that the silicated contact phase, of the first metamorphism, may represent a considerable zone thus crowded together. As one stands on the edge of one of the large laccoliths in this district and is asked whether the 60-foot silicated phase represents an original 300 feet or original 80 or 90 feet, the difference linearly is so small as to have little influence on one's judgment.

The compressional and relaxational periods seem not to have been sharply differentiated. From the available evidence, the first period of solution, diminution of volume, and essential lack of precipitation of materials from without, merged imperceptibly into the phase of introduction and precipitation of materials from without and maintenance or increase of volume. In view of this merging of earlier and later conditions, it is not to be expected that quantitative determinations will disclose exactly the proportions necessary on the assumption that the limestone had been dissolved, leaving its residual impurities. Suggestive accordance in silica-alumina ratios is all that should be looked for. In the case of the analyses of the Iron Springs report, the authors have been surprised that the accordance in ratio is so close.

We do not wish to be understood as arguing either that the

hypothesis offered to explain the Iron Springs contact phase of limestone has been finally established by quantitative data, for clearly more data are desirable, or that other hypotheses on similar contacts in other districts are thereby rendered less probable.

C. K. LEITH.

UNIVERSITY OF WISCONSIN.

THE DISSEMINATED LEAD DEPOSITS OF MISSOURI.

REPLY TO REVIEW BY F. L. RANSOME.

Sir: There seems to be a lack of fairness in the review of the report on The Disseminated Lead Deposits of St. Francois and Washington Counties, by F. L. Ransome, which prompts me to reply thereto.

In the first place, the columnar sections referred to would probably have passed without criticism had the figures been omitted as is usually the case. The attempt however, to give the reader at a general glance some idea of the composition of the formation in addition to the detailed descriptions has led Mr. Ransome to regret that the two were not so apportioned and arranged as to be referable one to the other. The fact is that the descriptions are so much longer, in some instances, than would admit of the same being placed opposite the portion of the columnar section to which it refers, that no attempt was made to carry this out. Anyone who is sufficiently interested can place the descriptions in the sections by using a scale.

In the case of the drawings of the thin sections, it was very unnecessary to state the magnification, since it was the intention to merely show the usual outline of the galena individuals as they occur in an ordinary piece of disseminated ore. The galena individuals vary so greatly in size that any magnification stated would apply simply to that particular section. The next section might contain individuals several or even a hundred times the size of the ones illustrated in the drawings.

Mr. Ransome's idea that the mine descriptions should have been used as an appendix simply illustrates that he is unfamiliar with the state geological survey situation. It would have been

the poorest kind of judgment to have placed this part of the report in an appendix.

Contrary to the statement made by Mr. Ransome that there is no chapter where "the essential characteristics of the ore deposits and the main facts upon which the scheme of genesis has been constructed," the reader is referred to the chapter on "Genesis of the Ores," pages 230 to 235, wherein is given all the essential characteristics of the disseminated ore bodies, upon which the theory of origin is based.

It might be inferred from Mr. Ransome's review that I had no problem of genesis to solve in connection with this investigation. The truth is that Mr. Jenney had published the theory that the ores of this district were derived from great depths and brought to their present place through the medium of ascending solutions; later Winslow brought forward the theory that the ores were essentially the result of descending solutions; and very recently Van Hise and Bain brought forward the theory that the ores were a result of "a first concentration by ascending waters and a second concentration by descending waters." That was the position in which I found the problem when I entered upon my investigations. Mr. Ransome must know that it is just as difficult to establish a theory of genesis under such conditions as it is to enter a virgin field and work out the same problem. Further it may be said that no one, not even Winslow, had previously worked out the stratigraphic and structural relations existing in that district, which are essential to support the theory advanced in the report which Mr. Ransome reviews.

The statement in the introduction to the report that "the hypothesis offered in explanation of the origin of the ores is not in any way original" would apply to any of the recently published reports on ore deposits of the mining districts. Yet where the public at large has three theories, not knowing which is the correct one, it appears to be of more than passing importance to have one or the other substantiated by additional evidence.

Mr. Ransome also criticizes the abundance of illustrations accompanying the report. His idea that the deposits are very

similar in all parts of the district was obtained from these same illustrations, and it was in order to bring out this fact, more than anything else, that the report was so profusely illustrated. I trust that others who glance over the illustrations accompanying the report will also appreciate the fact that the ores are essentially the same from all parts of the district. If they do, the illustrations will have served their purpose and justified their publication.

E. R. BUCKLEY.

THE ORIGIN OF PETROLEUM.

DISCUSSION OF PAPER BY LEONARD V. DALTON.

In a recent number of ECONOMIC GEOLOGY (Volume IV., No. 7) I find a very interesting and important article on "The Origin of Petroleum," by Mr. Leonard V. Dalton.

In this article Mr. Dalton refers to many works on geology and chemistry published in various languages, but I am surprised that he evidently has never seen my writings on this subject, since he nowhere mentions them.

In my treatise "Kritische Bemerkungen über die modernen Petroleum-Entstehungs-Hypothesen" (*Ztschr. für prakt. Geol.*, Berlin, 1898, März), I undertook a special and detailed criticism of the Höfer-Engler theory, and proved that Engler's experiments demonstrate definitely the impossibility of the animal origin of petroleum, and I then urged that the theory of the vegetable origin of petroleum through the fermentation of cellulose, brought forward by Radziszewski in 1877, had much in its favor.

In my later writings—"Ueber die Enstehung des Flysch" (*Ztschr. f. prakt. Geol.*, Berlin, 1901), "Die goelogischen Verhältnisse von Boryslaw" and "Die geologischen Verhältnisse der Erdölzone Opaka-Schodnica-Urycz" (*ibid.*, 1904)—I presented the same views, and especially in explanation of the Galician petroleum deposits, for which in my opinion the Engler-Hofer theory cannot be considered sufficient.

I am the more surprised that Mr. Dalton has entirely overlooked all my publications, since they have been published in

English either in translation or in detailed extracts in the *London Petroleum Review,* while Engler has, on the basis of my criticism, considerably modified his pure animal origin theory, and so to speak, "vegetablized" it, and Höfer contends against my views, both in the second edition of his "Das Erdöl und seine Verwandten" (Braunschweig, 1906) and in the recent work, "Das Erdöl, seine Physik, Chemie, Geologie, etc., von Engler und Höfer" (Band II., Leipzig, 1909).

I think that Mr. Dalton would have in many respects modified or extended his views on the origin of petroleum if the observations which I have mentioned above had been known to him.

Can you kindly see that these lines find a place in your journal?

RUDOLF ZUBER.

UNIVERSITÄT, LEMBURG, AUSTRIA.

REVIEWS

Through the Yukon and Alaska. By T. A. RICKARD. Mining and Scientific Press, San Francisco, 1909. Pp. 392.

This volume, as the preface states, is a record of observations made in the course of a journey through Yukon Territory and Alaska during the summer of 1908. It portrays that great northern province as seen by the mining engineer, and as mining is the principal industry of the region, it is peculiarly appropriate that this latest work on the northland should come from the pen of a member of the mining profession.

The book has a graphic style that holds the attention from cover to cover, even through descriptions dealing with technical phases of mining; pictorial attractiveness is assured by a generous number of illustrations. Narrative form is employed and as a rule only such matters are described as fell under the observation of the author. Where, however, localities rich in historical associations were visited, he has permitted himself a number of digressions into the past, such as that concerning the Russian attempts at colonization of California from Sitka, the stampede to Dawson, and the period of anarchy at Nome. He displays a remarkable facility to absorb local details, to feel and appreciate the spirit of the great North, and his pages therefore picture the region to the reader in all its local color.

The work makes no claim as a treatise upon the province, nor upon any single feature of the province. Much attention is given to mining, and more particularly to placer gold mining, which, having been confronted with problems peculiar to high northern latitudes, has developed a technique of its own. The volume will therefore appeal most strongly to those interested in the development of the mineral resources of the far North.

The opening pages deal with southeastern Alaska; two chapters are devoted to the Treadwell group of mines, which is situated on Douglas Island opposite Juneau. Emphasis is laid upon the policy of the management to maintain the physical comfort and social welfare of the laboring force at the highest possible standard. This is said to be superior now to that of any gold mine in the world.

The Alaska Perseverance mine, nestled on the walls surrounding the amphitheater of Silver Bow Basin back of Juneau, is deemed worthy

of a full-page illustration, but receives no mention in the text. This is an unfortunate omission in a volume that devotes so large a share of space to the mining development of the territory. The Perseverance, with its 100 stamps and the Alaska-Juneau, with its 30, are treating ores that are more typical in character of the Juneau gold belt than are those of the Treadwell albite-diorite dike. It is worthy of note that the Alaska-Juneau has been operating at a profit for a number of years on ore averaging in value little more than half of that of the much-famed low grade ore of the Treadwell deposit.

Skagway, White Horse and the trip to Dawson are described; the Klondike is given several chapters. The chapter on the development of mining methods is especially valuable, and the description of the invention of the steam point and the evolution of the methods of drift mining in frozen gravels is unexcelled. The construction of the seventy-mile Yukon ditch, which is designed to aid the exploitation of the Klondike gravels, is gone into in some detail and elicits the evident admiration of the author.

From Dawson the narrative proceeds to Fairbanks, the metropolis and placer-mining center of Alaska, and from Fairbanks to Nome on Seward Peninsula. Several chapters are devoted to the description of Nome and its environs, and to the stirring history of the discovery of the golden beaches. Incidentally a somewhat unsympathetic picture of the Eskimo is presented. The book closes with an account of a trip to the Solomon-Council region east of Nome, where especial attention was given to certain pioneer examples of successful gold dredging on Seward Peninsula.

ADOLPH KNOPF.

Iron Ores, Fuels, and Fluxes of the Birmingham District, Alabama. By ERNEST F. BURCHARD and CHARLES BUTTS. With chapters on the Origin of the Ores, by EDWIN C. ECKEL. Bull. U. S. Geol. Survey, No. 400, 1910. Pp. 204.

The Birmingham district is nearly unique in containing all the essentials for the development of the iron and steel industry—iron, fuel and fluxes. The present report, covering all of these raw materials, likewise has a scope not often found in reports of the United States Geological Survey.

The Clinton iron ores are the most important element in the situation. These are adequately mapped and described. The chemistry and physical characteristics of the ore are more fully described than in any report heretofore published. The ores are regarded as original sedimentary deposits for the following reasons:

1. In mining from slopes running down on the dip of the ore bed, when once the limit of surface weathering is passed—and this may be at any point from 1 to 100 feet below the outcrop—no further important change in the ore is found with increasing depth; though a number of mine workings are now close to 2,000 feet from the outcrop.

2. A number of borings in Alabama have struck the ore at points from one half to 1 mile back from the outcrop, and at depths of 400 to 800 feet below the surface. The ore encountered in these borings was hard ore of the usual quality, and not merely a "ferruginous limestone." Several borings in New York have struck Clinton ore at distances of from 10 to 15 miles back from the outcrop. These borings showed good hard ore at depths of 644 to 995 feet below the surface.

3. The physical character of the oölitic ore can not readily be explained on any replacement theory, while the formation at the present day of original oölitic materials is a matter of common knowledge.

4. The occurrence of fragments of the ore in overlying beds of limestone in the Clinton formation, as described by Smyth,[1] points to the fact that the ore had been formed prior to the deposition of this limestone.

5. If the replacement theory were accepted, one would expect that the ore beds would show a greater vertical range; that is, that they would at places occur in rocks of other than Clinton age. Throughout their entire extent the Clinton beds are closely associated with Silurian and Devonian limestones and shales, some of which offer excellent receptacles for replacement deposits, but the characteristic red ores are confined to the Clinton itself.

Alternative hypotheses, that the beds are merely the weathered outcrops of slightly ferriferous limestones, or that the ores are much later in origin than their inclosing rocks, are considered and rejected.

In discussion of general geology the iron ores are described as shallow water deposits developed in embayments and channels near the shore. Their longer dimensions are parallel to the shore. Cross sections along any dimension are lens-shaped, as are those of any other sediments. No attempt is made to ascertain the conditions of deposition necessary to the development of these peculiar beds.

There seems now to be little reason to doubt, from facts brought out here and elsewhere, that the Clinton ores are substantially original sedimentary deposits. This carries our attention back to the source of the sediments and the conditions of their deposition. This problem is yet to be solved. It is to be hoped that the U. S. Geological Survey will take up this problem in its further work on the Clinton ores.

[1] *Am. Journ. Sci.*, Vol. 43, 1892, p. 493.

The conclusion as to the original sedimentary character of the ore figures largely in estimates of ore reserves. If this origin be a true one, no regular decrease in iron content is to be expected as the ore beds are explored to greater depths than those already attained. Also the shape and extent of the beds are probably comparable with those of the sandstones and shale lenses with which the iron ores are associated. On this basis there is estimated 796,896,800 long tons of red ore in the Birmingham district. About 80 per cent. of the ore of the state is concentrated in this district.

The brown ores are mined to a less extent. Their characteristic associate is clay. They are regarded by Eckel as the result of weathering of a limestone in which there had been some previous concentration of iron ore. It is not specifically stated whether these original deposits in limestone are sedigenetic or secondary. In either case the ultimate source is not discussed.

Physical and chemical characteristics of the coke and coal of the Warrior Basin cold field (the one now supplying the blast furnaces) are described and an interesting comparison made with the coals and cokes of Pennsylvania and West Virginia. The Alabama coals compared have higher ash and sulphur and less volatile matter than the Connelsville coal. In supporting power and uniformity they compare well with the Pennsylvania coals. The total available tonnage is estimated to be greater than that necessary to smelt all available iron ores of the district.

Dolomite is much more extensively used than limestone as a flux in this district, and advantages are cited for the use of dolomite. The quantity of good dolomite to be had under present quarrying conditions is practically inexhaustible.

C. K. Leith.

SCIENTIFIC NOTES AND NEWS[1]

PROFESSOR R. A. DALY, of the Massachusetts Institute of Technology, gave five lectures to advanced students in the Geological Department of the University of Wisconsin in January on the subject of "Igneous Rocks."

V. F. MARSTERS is at present engaged in the investigation of a section in southern Peru, and will not return to the United States for several months. His address is Apartado 856, Lima, Peru.

J. B. TYRRELL, of Toronto, has been delivering a short course of lectures on "The Structure, Origin and Distribution of Placer Gold Deposits" before the students of economic geology in McGill University, Montreal.

MR. PHILIP ARGALL announces that he has entered into partnership with Philip Henry Argall, late of Selby Smelter, and George Oates Argall, of Leadville, Colo., for the purpose of conducting a general business of consulting, mining and metallurgical engineers, under the name of Philip Argall and Sons.

THE WEST VIRGINIA GEOLOGICAL SURVEY has recently published the Detailed County Report, covering Marshall, Wetzel and Tyler counties, with a case of soil, topographic and geologic maps. This publication is sent out on receipt of 35 cents to cover cost of delivery.

[1] Geologists, mining engineers and others interested in applied geology are invited to keep the editor informed of new investigations of mining districts or scientific studies undertaken by them, together with such other scientific and personal items as may come to their notice.

AT A MEETING of the Geological Society of Washington held February 23, 1910, a paper was read by A. C. Spencer on "Igneous Metamorphism," also one by Howland Bancroft on "Platinum in Southeastern Nevada."

AT A MEETING of the same society on March 10, the following papers were presented: F. B. Laney, "A Microscopical Study of Some Sulphide Ores"; F. G. Clapp, "A Proposed Classification of Petroleum and Natural Gas Fields, Based on Structure"; J. H. Gardner, "Some Notes on the Mammoth Cave, Kentucky."

MR. E. F. BURCHARD attended the Cement Products Exposition in Chicago the latter part of March for the purpose of obtaining statistics on the cement production of the United States and noting the development of the cement industry, as shown by the exhibits. He also attended the Pittsburg meeting of the American Institute of Mining Engineers and read a paper on Field Investigation of Structural Material by the U. S. Geological Survey.

MR. E. C. ECKEL, president of the Dominion Portland Cement Company, has been in Winnipeg and the country to the northwest the past few weeks for the purpose of locating three plants which the company proposes to erect in the near future.

PROFESSOR HENRY LANDES, State Geologist of Washington, recently spent a few days at the national capital, arranging for co-operative topographic and geologic work between the State Survey of Washington and the U. S. Geological Survey and other Federal bureaus.

W. C. MENDENHALL spent part of the month of March investigating underground water resources in the vicinity of Grand Falls, Texas.

GEORGE C. MATSON, of the U. S. Geological Survey, has been doing geologic work in Florida the past three months.

W. C. PHALEN made an examination of the burrstone quarries in the southwestern part of Virginia the latter part of March for the mineral resources of the U. S. Geologcial Survey.

MESSRS. C. W. WASHBURNE, E. B. HOPKINS and E. L. DEGOLYER, who are on furlough from the U. S. Geological Survey, are at present employed in mapping topography and geology for the Cia. Mexicana de Petroleo, "El Aguila," S. A. Their address is Apt. 150, Tampico, Tamps, Mexico.

MR. G. O. SMITH, director of the Geological Survey, delivered an address before the Conservation Congress at St. Paul the middle of March.

MESSRS. F. L. RANSOME and J. D. IRVING attended the recent meeting of the Canadian Institute of Mining Engineers held at Toronto on March 2, 3 and 4.

ROBERT ANDERSON has recently completed an examination of certain townships in southwestern Utah which had been withdrawn as oil land.

THE COAL LAND CLASSIFICATION BOARD of the U. S. Geological Survey at present consists of four men instead of three. They are A. C. Veatch, chairman, G. H. Ashley, W. R. Calvert and A. R. Schultz.

R. H. SARGENT, topographer of the division of Alaska mineral resources of the U. S. Geological Survey, is giving a six weeks' course in topographic surveying at the University of Chicago this spring.

AN APPRECIATION of the need of topographic work in the development of mineral resources is shown in the fact that Mr. Fred McLaughlin, a topographer of the U. S. Geological Survey, has recently gone to the Isthmus of Tehuantepec to inaugurate topographic surveys for S. Pearson & Son in connection with their work in the oil fields.

C. A. FISHER, of the geologic branch of the U. S. Geological Survey, has resigned his official position and formed a partnership with Ralph Arnold of Los Angeles. The firm will open an office in Denver as oil experts, and Fisher will have charge of their work in the Rocky Mountain region, while Arnold will devote his attention as formerly to the California oil fields.

A NEW BUILDING for the U. S. Geological Survey is again being urged before Congress. The present buildings have been inadequate for a number of years and certain branches have been housed in the Pension Office and elsewhere. At present the Rocky Mountain and Pacific Coast divisions of the topographic branch are occupying rooms in the Munsey Building on Pennsylvania Avenue, but the main building and annex are still excessively crowded. The continual and steady growth of the bureau is suggested by the correspondence which increases from 8 to 12 per cent. annually. The receipts of money for publications amounted to over $1,600 for the month of February, and the output of maps, folios and smaller printed pieces from the printing and engraving division ranges from 175,000 to 250,000 pieces per month. The present buildings are not fireproof and constantly jeopardize property valued at over $5,000,000.

DR. T. C. CHAMBERLIN, professor of geology in the University of Chicago, has been elected president of the Geological Society of Chicago.

PROFESSOR R. A. DALY, of the Massachusetts Institute of Technology, gave five lectures to advanced students in the Geological Department of the University of Wisconsin in January on the subject of Igneous Rocks.

WILLIAM GEORGE TIGHT, professor of geology and natural history at Denison University from 1887 to 1901 and since then until a few months ago president and professor of geology at the University of New Mexico, fellow of the Geological Society of America and of the American Association for the Advancement of Science, died at Glendale, Cal., on January 15, at the age of forty-five years.

AT McGill University the following are acting as special lecturers during the present session:

Professor J. F. Kemp, of Columbia University, on "The Application of Geology to certain Engineering Problems."

J. B. Tyrrell, Esq., F.G.S., on "The Geological Relations of Alluvial Gold Deposits, as Illustrated more Particularly by those of the Yukon District."

D. B. Dowling, Esq., of the Geological Survey of Canada, on "The Geology of Coal, with especial reference to the Coal Deposits of the Province of Alberta."

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